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SIMULATED APPROACH MARCHES DURING THERMAL STRESS:

A P^2NBC^2 STUDY

U S ARMY RESEARCH INSTITUTE OF ENVIRONMENTAL MEDICINE

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A P^2NBC^2 sponsored study of eight subjects on simulated 12 mile approach marches in MOPP-0, MOPP-1 and MOPP-4 was conducted at Fort Bliss, Texas in August, 1991. The P^2NBC^2 objective is to study physiology and psychology within the context of militarily relevant tasks in the NBC environment. The focus of the present study was model evaluation, but the study included simulated marksmanship performance in MOPP-0 and MOPP-1, and data collection for thermal features modeling. Data include rectal temperature, surface skin temperatures, heart rate, and body water loss. Subjects wore MOPP-0 and MOPP-1 CP ensembles during day and night test sessions, and MOPP-4 on one daytime session. Weather data were collected on-site and simultaneously at a remote site for development of a thermal features remote sensing program. For the daytime MOPP-1, only one subject completed a 12 mile march. In MOPP 4, the longest endurance time was 3 hours and 24 minutes. For the test scenario, heat strain at night was minimal. The marksmanship performance tests indicate a cumulative effect of time. There was general agreement, varying within an overall mean prediction error of -0.2 to 0.43°C, between observed subject rectal temperatures (T_{re}) and results predicted from the P^2NBC^2 Heat Strain Decision Aid (HSDA).

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U.S. ARMY RESEARCH INSTITUTE
OF
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A P^2NBC^2 sponsored study of eight subjects on simulated 12 mile approach marches in MOPP-0, MOPP-1 and MOPP-4 was conducted at Fort Bliss, Texas in August, 1991. The P^2NBC^2 objective is to study physiology and psychology within the context of militarily relevant tasks in the NBC environment. The focus of the present study was model evaluation, but the study included simulated marksmanship performance in MOPP-0 and MOPP-1, and data collection for thermal features modeling. Data include rectal temperature, surface skin temperatures, heart rate, and body water loss. Subjects wore MOPP-0 and MOPP-1 CP ensembles during day and night test sessions, and MOPP-4 on one daytime session. Weather data were collected on-site and simultaneously at a remote site for development of a thermal features remote sensing program. For the daytime MOPP-1, only one subject completed a 12 mile march. In MOPP-4, the longest endurance time was 3 hours and 24 minutes. For the test scenario, heat strain at night was minimal. The marksmanship performance tests indicate a cumulative effect of time. There was general agreement, varying within an overall mean prediction error of -0.2 to 0.43°C, between observed subject rectal temperatures (T_{re}) and results predicted from the P^2NBC^2 Heat Strain Decision Aid (HSDA).

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CONTENTS

Section	Page

Section	Page

Section	Page

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

A P^2NBC^2 sponsored study of eight subjects on simulated 12 mile approach marches in MOPP-0, MOPP-1 and MOPP-4 was conducted at Fort Bliss, Texas in August, 1991. This report presents the database and documents the study procedures and methods. The primary objective of this study is to provide data for current and future model development. The P^2NBC^2 objective is to simultaneously study physiology and psychology within the context of militarily relevant tasks in the NBC environment. The focus of the present study included model evaluation, modification and/or partial validation. The study was expanded to encompass data collection for thermal features and task performance measurements. Data are presented on the physiological responses of eight subjects while walking on a fixed oval track at 1.1 $m \cdot s^{-1}$ while carrying a 22 kg fighting load. Data measured on individual dataloggers include rectal temperature, surface skin temperatures and heart rate. Water consumption was recorded and weights were taken to calculate body water loss. Subjects walked for 24 minutes, then stopped and participated in a marksmanship related test during a 6 minute rest break. The objective was to complete a 12 mile (6 hr) march during each test session. Subjects wore MOPP-0 and MOPP-1 CP ensembles during both day and night test sessions, but MOPP-4 level protection on only one daytime session. Subjects did not participate in marksmanship tests in MOPP-4. Comprehensive weather data were collected at an on-site meteorological station and WBGT monitors. WBGT data were simultaneously collected at a remote site for development of a thermal features remote sensing program. A brief evaluation compares the data to predictions based on the P^2NBC^2 Heat Strain Decision Aid (HSDA). No subject withdrew due to exceeding the pre-selected maximum core temperature (39°C) or maximum heart rate (180 BPM) limits. For the daytime MOPP-1 condition, only one subject completed the 12 mile march. In MOPP-4 condition, the longest endurance time was 3 hours and 24 minutes. Our results indicate that physiological heat strain at night, for the test scenario, was minimal. The performance tests related to marksmanship indicate that there was a cumulative effect of time in both night and day tests. The data reflect the importance of environmental conditions. Daytime environments were very dynamic, whereas, night environments tended to be more stable. There was general agreement, varying within an overall mean prediction error of -0.20 to 0.43°C, between observed subject rectal temperatures (T_{re}) and results predicted by the P^2NBC^2 Heat Strain Decision Aid (HSDA).

I. INTRODUCTION/OVERVIEW

I.A. OBJECTIVES

This study had three basic objectives. The first was to develop a physiological database for the evaluation and continued development of thermal models. The physiological measurements were rectal temperature, skin surface temperatures, heart rate and water balance data. The second objective was to develop a database for thermal features modeling by collecting meteorological data at the test site and a remote grid. The third objective was to evaluate the effect a gross motor activity (walking) had on a fine motor activity (marksmanship) while operating for a sustained period.

I.B. P^2NBC^2 PROGRAM

The study was funded by The U.S. Army Chemical School's P^2NBC^2 program. P^2NBC^2 is an acronym for the Physiological and Psychological Effects of the NBC Environment and Sustained Operations on Systems in Combat. The system under study is the Soldier System consisting of soldiers in three levels of mission orientated protective posture (MOPP) carrying a 22 kg "fighting load" in a combat configuration (personal weapon, helmet, load-bearing (LBE) equipment, combat clothing). The NBC environment consists of wearing MOPP-0, MOPP-1 and MOPP-4 levels of chemical protection during both day and night conditions in a hot-dry climate (Fort Bliss, TX). The sustained operation is a 6 hour, 12 mile "approach march" simulation.

I.C. THERMAL PHYSIOLOGY

Heat injury is a very real concern of the military. During military training, especially in warmer climates and summer conditions, many military personnel have observed or experienced heat injury. Heat casualties are not entirely restricted to warm climates or season; injury may also occur in the winter if heavily clothed personnel are engaged in strenuous activity. In both warm and cold environments, dehydration is often a contributing factor to heat injury. The following paragraphs present a brief, simplified explanation of the biophysics and physiology of thermal stress (Santee and Gonzalez, 1988).

The physiology of heat injury may be explained in terms of a heat balance equation:

$$\pm S = M \pm C \pm K \pm R \pm E \pm W \quad \text{[Watts]}$$

The preceding equation defines heat storage (S) as a function of the interaction of the other terms in the heat balance equation. The storage term (S) is directly related to the change in body temperature. If more heat is produced metabolically than is lost to the environment, the storage term reflects an increase in the energy level of the body mass, hence body temperature increases. A change in heat storage reflects a shift in the relationship between the other components of the heat balance equation.

Stresses are the external factors such as high air temperature, high humidity and solar radiation that tend to skew the energy equation in the direction of increasing heat storage (S). Strain is essentially the physiological costs of thermoregulation and rising body core temperature as an organism responds to those stresses. An environment is "thermoneutral" when the thermoregulatory mechanisms of the body are able to counter the effects of external stresses (maintain homeostasis) without an increase in metabolic cost. Heat injury occurs when the body is unable to maintain homeostasis and the rising internal temperatures begin to affect physiological processes, and ultimately, the biochemistry of the body. In extreme cases, internal

body temperatures become high enough that proteins are denatured, causing irreparable damage and possible death.

Metabolism (M) is the heat produced internally as a by-product of energy production for maintenance of body functions plus the energy cost of activities. Standard values for activities such as sleep, rest, running or load carriage are known for military populations (USARIEM Technical Note 91-2, 1990). Metabolic heat production, as a physiological parameter, is either estimated on the basis of the type and intensity of activity or measured directly. Heart rate is related to the level of physical activity, and hence to metabolic rate, but there is disagreement among physiologists concerning the use of heart rates to quantify metabolic heat production. External work (W) is dependent on load, terrain grade and speed of movement. The work term on level terrain is considered to be near zero.

Heat exchange via convection (C) and conductance (K) are dependent on the difference between body surface temperatures and the environmental medium in contact with the surface. Clothing moderates the rate at which heat can be transferred between the body surface and the surrounding environment. Skin and body core temperature are the physiological parameters that affect convection and conductance. The greater the temperature difference between a body and the surrounding environment, the greater the rate of heat exchange. If there is no difference between body temperature and the surrounding environment, there is no net heat exchange. In addition, core and surface temperatures are integrated into the thermoregulatory control system, which may then impact metabolic rate. Both convection and conductance are also dependent on the temperature of the air or surface in contact with the body, but these are physical properties of the environment, not physiological properties of the body. Convective heat loss is also dependent on air density and the speed of air movement (wind).

The radiation (R) term consists of incoming and outgoing components. The amount of incoming solar and thermal radiation absorbed is dependent on the characteristics of the body surface or clothing, the intensity of the radiation sources

and area exposed to the radiation. Outgoing thermal radiation is a function of surface temperature.

Evaporation (E) of sweat is a very important thermoregulatory mechanism in humans for alleviating heat strain. Sweat evaporation is dependent on the humidity gradient between the skin surface and the ambient humidity of the surrounding environment. As ambient humidity increases, sweating becomes a less effective pathway for cooling the body. Clothing, especially chemical protective clothing, may reduce the quantity of sweat which can be evaporated from the body surface through the clothing, thereby reducing the effectiveness of sweating as a mechanism to transfer heat from the body to the environment. Evaporative heat loss is also dependent on the thermoregulatory control of sweat production and the availability of internal water. If water lost by sweating is not replaced, dehydration occurs. In cases of extreme dehydration, an individual is no longer able to sweat, and the heat which would be lost by evaporation is stored within the body mass.

The biophysics and physiology of heat stress dictated the parameters which were collected during this study. Rectal and skin surface temperatures are related to body temperatures, which in turn, relate to convection, conductance, thresholds for sweat production, feedback in thermoregulatory systems and the degree of heat strain. Heart rate is closely related to the level of activity, metabolic rate and thermal strain. Short term changes in body weight provide an indication of water intake, sweating, dehydration and evaporative cooling. Physical parameters of the environment which impact the heat exchange between an organism and its environment are air and surface temperatures, wind speed, humidity and radiation. Those parameters define the thermal environment of an organism (Santee and Gonzalez, 1988).

I.D. HEAT STRAIN MODELS

Heat injury may have a significant negative impact on military training and operations (Steinman, 1987). Military planners are aware that strenuous activities in a hot environment while wearing chemical protective clothing will result in an increased potential for heat casualties. The development of mathematical models which predict when environmental conditions present a potential heat injury risk is an important research effort. A model can provide a quantitative prediction of those risks to allow consideration of alternative strategies and to plan for water supply, casualty evacuation and treatment.

I.D.1 Historical Perspective on Models

A model is a representation of the function of a system. Models may be descriptive, mathematical, or physical. This study is concerned with mathematical models of soldiers' physiological responses to a thermally stressful environment. Although they may be very complex mathematically, models are normally a simplification of the real system. A common assumption in modeling is that models do not completely replicate the actual function of a system (Pease and Bull, 1992).

There are two basic types of heat stress models; rational models and empirical models (Gonzalez, et al., 1974). Rational models are derived from first principles; an understanding of the physical laws that govern the biophysics of heat exchange between an organism and its environment. Examples of rational models include operative temperature (Winslow, et al., 1937), and other equivalent temperatures (Gonzalez, et al., 1974). Rational models attempt to calculate a solution that is based on the actual mathematical heat balance equation. An empirical model may apply knowledge of first principles, but the actual model is derived directly from the relationship between causal factors and an actual database. The Wet Bulb Global Temperature (WBGT) index (Yaglou and Minard, 1957) is an empirical model.

From the perspective of this study, our primary concern is the evaluation and refinement of the final product, the heat strain models, rather than an in depth description of specific models. The USARIEM heat strain model and the P^2NBC^2 heat strain decision aid are described in detail in other references (Pandolf, et al., 1986, Gonzalez and Stroschein, 1991; McNally, et al., 1991). The basic model is derived from the empirical Givoni and Goldman (1972) model for predicting equilibrium core temperatures for specific environmental conditions.

Although it is beyond the scope of this study to compare the rational and empirical approaches to modeling, it may suffice to say that rational models are theoretically more robust because they can be modified. Empirical models are frequently a more pragmatic method to describe a specific system. The empirical solution is, however, very dependent on the limitations of the original database. Extension of an empirical model beyond the constraints of the source database requires careful evaluation with an independently derived database. Hence the need to fulfill objective one of this study, the development of a database for thermal model evaluation and development.

I.D.2 The P^2NBC^2 implementation of the USARIEM heat strain model

The USARIEM model was developed specifically for the military user. The model can provide guidance, based upon climatic conditions, for planning operations. Given a set of meteorological conditions, the clothing worn by personnel and the level of activity, the P^2NBC^2 implementation of the model calculates output as maximum work time or tolerance, a work/rest cycle which will allow sustained activity in that environment, water consumption requirements, and equilibrium core temperatures for work and rest. The model also outputs the heat casualty rate expectation if the work/rest cycle is not implemented.

Because a partial evaluation of the P^2NBC^2 derived decision aid was part of this study, a brief description of the model input parameters and output is warranted. The

decision aid is written in the Ada programming language for a DOS personal computer. The model is run from a menu display which requires the user to select input parameters from secondary menus or to input parameters directly. Basic environmental input consist of air temperature, humidity, wind speed and estimated solar radiation. Inputs related to the soldier system include activity level or task, acclimation status and clothing. The user may also select a casualty risk level ranging from light to heavy depending on operational considerations. During routine training, only a low level of potential heat injury is acceptable, but in a combat environment, a higher risk of heat injury may be acceptable to achieve a specific mission.

I.E THERMAL FEATURES

Across theater wide regions, air temperature, humidity, wind speed, and solar radiation may vary from place to place and from hour to hour. An understanding of the physiologically significant variation in environmental parameters at militarily relevant spatial and temporal scales is a key element in defining the weather data requirements needed to support the effective use of predictive models such as the P^2NBC^2 Heat Strain Decision Aid in real world military settings. Using a modification of the USARIEM heat strain model and standard weather information from a theater scale area in Southwest Asia for the month of August, the existence of spatially and temporally dynamic zones of high thermal injury risk has been demonstrated (Matthew and Santee, 1991). This study provided an opportunity to evaluate the thermal feature concept in the context of diurnal variations across much smaller, but still militarily relevant, spatial scales of up to 35 km.

I.E.1 Thermal Features and Remote Sensing

Ultimately, the ability to identify and display thermal features as terrain map overlays is consistent with the broad objectives of emerging tactical weather information systems such as the Army's Integrated Meteorological System (IMETS)

(Brown, R.C. and J.E. Harris, 1990). The acquisition and utilization of satellite derived environmental data is a planned capability of IMETS. Existing polar orbiting weather satellites can provide environmental data at surface resolutions of 1 km, across a swath that is several thousand km wide. The ability to utilize satellite data to identify and map regions of high thermal injury risk could significantly improve decisions related to soldier performance in military operational settings and could be supportable by IMETS. This study provided a unique opportunity to build on previous work (Schatzle et al., 1989) and evaluate the strengths and limitations of this important technology in the context of concurrent human thermal response measurements and extensive surface level "ground truth" data.

I.F. MARKSMANSHIP PERFORMANCE

The purpose of this portion of the study was to assess the individual and combined effects of two different clothing ensembles, while exercising in a hot-dry environment, on rifle marksmanship and other fine motor control skills. Militarily relevant data collected in the field to validate laboratory research is necessary to bridge the gap from the lab to battleground.

The soldier who is required to fire a rifle under a chemical threat in a sustained operation has a number of stressors which are likely to affect his success. The effects of heat, clothing, and exercise state can have profound effects on marksmanship performance. Heat impairs marksmanship accuracy due to degradation of muscular control (Johnson and Kobrick, 1988). Furthermore, it has been shown that soldiers exercising in the heat that lost the greatest amount of body weight or who did not rehydrate fully, had the most severe decrements to rifle marksmanship accuracy (Tharion, et al., 1989). Clothing has also been a factor. Tharion, et al. (1989) reported marksmanship accuracy was significantly impaired while wearing MOPP-4 after walking on a treadmill at 1.1 $m \cdot s^{-1}$ (2.5 mph) in a 33°C (91°F), 20% humidity environment. No decrement was observed in MOPP-0. Exercise also disrupts marksmanship accuracy by an increase in body tremors

associated with fatigue and an elevated heart rate (Tharion, et al., 1992; Knapik, et al., 1991). The problems of accurately firing a rifle have been attributed to an increase in body sway after exercise (Niinimma, and McAvoy, 1983).

II. METHODS AND MATERIALS

II.A. TEST LOCATION

The site selected for the study was Fort Bliss, Texas. Because data on physiological responses in chemical protective posture in hot dry environments are especially relevant to issues arising from the Army's experience during Operation Desert Storm, and because physiological performance data at or near accepted environmental limits of human tolerance are of special importance in evaluating the model, this study was conducted in a location where such conditions were likely to persist over the course of several days. Fort Bliss is in the El Paso, Texas area where the 30 year (1951-80) monthly average temperature in July is about 21.8°C (82.6°F) (NOAA, 1983). The highest recorded temperature for Texas is 49°C (120°F) (NOAA, 1983).

II.B. DESIGN AND BASIC TEST SCENARIO

There was one basic test exercise scenario which consisted of a simulated route or approach march of 12 miles to be completed in 6 hours. The basic test scenario was repeated for five discrete combinations of environmental exposure and clothing (Table II-1) while carrying a 22 kg "combat load" (Section II.E, Table II-3). These combinations were night marches in MOPP-0 and MOPP-1, and day marches in MOPP-0, MOPP-1, and MOPP-4. The marksmanship tests were integrated into the basic march as described in Section II.D.2.3.1.

Table II-1. March scenario by time of day and clothing.

Night 13 & 20 AUG 91	Day 16,17 & 18 AUG 91
MOPP-0	MOPP-0
MOPP-1	MOPP-1
......	MOPP-4

II.C. TEST SUBJECT SELECTION

Ten healthy young male subjects (ages 19-28 years) were selected from the NATICK volunteer subject population. Prior to any experimental testing, all subjects were medically screened and familiarized with test procedures. Nine subjects traveled to Fort Bliss, but only eight subjects participated on each test day. The other test subject was available as a replacement to maintain the sample population size if one of the initial subjects was unable to participate.

II.D. MEASUREMENTS ON HUMAN SUBJECTS

II.D.1 Measurements and Procedures at USARIEM

Prior to travel to Fort Bliss for outdoor testing, the testing began with peak $\dot{V}O_2max$, hydrostatic weighing, acclimation and determination of metabolic rates while walking on a treadmill with and without a backpack at NATICK.

II.D.1.1 Acclimation. All subjects were heat acclimated prior to travel to Fort Bliss by walking on a level treadmill at 1.56 $m \cdot s^{-1}$ (3.5 mph) with environmental test chamber conditions at 49°C (120°F), 20% rh and 1.1 $m \cdot s^{-1}$ wind speed. Their 115 minute exposure was divided into a 5 minute standing baseline, and two 50 minute walk sessions separated by a 10 minute rest period. Subjects wore gym shorts and boots. They were provided water *ad libitum*. Acclimation methods are derived from Pandolf, et al., 1988. Subject nude body weights were recorded daily to establish a baseline for monitoring subjects for dehydration. Body weights for subjects participating in other studies were obtained from the investigator for those days (Roberts, personal communications).

II.D.1.2 Subject Participation. Although ten test volunteers were recruited from the NATICK volunteer subject pool an unanticipated delay in the completion of another study allowed only four subjects to be available for the first two days of scheduled acclimation. The other subjects became available and began participation on the third day.

II.D.1.3 $\dot{V}O_2max$ Testing. Peak $\dot{V}O_2max$ was determined by direct measurement using the continuous incremental treadmill-running method (Pandolf, et al., 1988). $\dot{V}O_2max$ values were obtained for four subjects during the pre-travel period and recent values for three other subjects were obtained from other investigators (personal communications, M. Sharp, D. Roberts). One subject was unable to participate in $\dot{V}O_2max$ testing.

II.D.1.4 Metabolic Rate Testing. During the acclimation period, metabolic rates were measured by collecting expired gases in Douglas bags and analyzed by open circuit spirometry (Pandolf, et al., 1988) on the final day of acclimation. On that day, the chamber temperature was 35°C (95°F). The treadmill speed was 1.1 $m \cdot s^{-1}$ (2.5 mph), and subjects walked on the level treadmill with and without a 20 kg packboard. Subjects wore boots and shorts during the metabolic rate measurements. When the

metabolic measurements were completed, the subjects walked for the remainder of the acclimation session at 1.6 $m \cdot s^{-1}$ (3.5 mph).

II.D.1.5 Hydrostatic Weighing. Of the nine final test participants, seven subjects were weighed by the immersion method to determine each subject's percent body fat. Due to a study conflict, two test subjects were unable to participate in the hydrostatic weighing. Estimates of their percent body fat, determined by skinfold measurements, were provided by Roberts (personal communications).

II.D.1.6 Marksmanship Training. Subjects were familiarized and trained with a NOPTEL ST-1000 (Noptel Ky, Oulu, Finland) marksmanship simulator during the acclimation period. Marksmanship testing is described in more detail below in the outdoor test procedures section. Training included "firing" practice test scores to establish a performance baseline.

II.D.2 Measurements and Procedures at Fort Bliss

II.D.2.1 Outdoor Acclimation And Practice. After arrival at Fort Bliss, the subjects participated in two more days of acclimation and familiarization at the test site prior to the first day of testing. Acclimation at the test site was to consist of a 110 minute exercise (50 min walk, 10 min rest cycles) in BDU's at 3 mph pace on 11 August 91, with water supplied ad libitum. Environmental conditions were cooler than anticipated (light rain) and the walk was terminated after 50 minutes. The second "acclimation" period, which began at 0400 hrs, was utilized as a familiarization exercise for testing under low light conditions. During this phase, subjects were also familiarized with the test site and methods for maintaining a constant walking pace. For safety purposes, subjects were fitted with a rectal probe and heart rates were monitored during field acclimation.

II.D.2.2 Daily Pre-Test Preparation. On test days, upon arrival at the preparation area, each subject was weighed nude and instrumented with a rectal probe, skin thermistors and ECG electrodes. In some cases, to safeguard against dehydration, test subjects were required to consume specified quantities of water to bring their initial body weight to within 0.45 kg (1 pound) of the average initial weight observed during the five days prior to travel to Fort Bliss. This requirement was imposed by the USARIEM Human Use Review Committee. After the subjects were instrumented and prepared for testing, they dressed in underwear and either Battledress Uniform (BDU) alone, or donned the CP Battledress Overgarment (BDO) over the BDU. On the MOPP-4 test day, only the BDO was worn over underwear. Subjects then donned their load bearing equipment. Raw sensor data were processed and stored on Grant SQ-32 electronic dataloggers (Rodahl et al., 1988) which were carried by each subject throughout the test scenario. The dataloggers provided a real time digital display of rectal temperature (T_{re}) and heart rate. As noted elsewhere (Section II.E) , the total weight of clothing and equipment averaged 22.3 kg for the entire study.

II.D.2.3 Outdoor Test Procedures. When completely dressed and equipped, the subjects left the preparation area and proceeded to the track. They were weighed again at the start line with full equipment. The subjects' objective was to complete a 12 mile simulated approach march. Their efforts were divided into 30 minute cycles. Each cycle consisted of 24 minutes of marching separated by 6 minute breaks. On a quarter-mile track, the subjects walked four laps and rested one lap every 30 minutes, for an effective marching speed of 2 mph (0.9 $m \cdot s^{-1}$). To achieve that effective speed with scheduled breaks, subjects walked four laps in 24 minutes at an actual speed of 2.5 mph (1.1 $m \cdot s^{-1}$), and actual lap time was 6 min. Rest stops were at one mile (1.6 km or 4 laps) intervals. All subjects walked at the same pace because most approach marches are not self-paced. Also, because the USARIEM model assumes a constant metabolic rate for a given activity, it was important that each individual maintain a constant work rate.

Subject rectal temperatures and heart rates were checked by staff at the fixed half-way check-point every 6 min and hand recorded. If either a rectal temperature of 39.4°C or a heart rate of 180 bpm had been observed, the subject's participation would have been stopped for that test day. Subjects were provided with a full canteen of water and were encouraged to drink freely during test sessions. Pre-measured (750 ml) canteens were available at the start-point every lap to be exchanged for depleted canteens. The amount of water consumed by each subject was determined at the end of the test period by tabulating the number of 750 ml canteens consumed, converting that value to a volume of water, then adding the amount consumed from the last canteen.

Subject starts were staggered to allow pairs of subjects to perform marksmanship testing during the rest period at the end of each 30 minute cycle. The first pair of subjects started out alone. As they completed each consecutive lap, another pair joined them at the start line. Thus for the initial lap there were two subjects, for the second lap four subjects, third lap six subjects and for the fourth lap all eight subjects were walking. When the first pair completed their fourth lap (one mile), they stopped at the start line for their rest period. When the other subjects completed the fifth lap, the initial pair rejoined the walk and the second pair stopped for their rest period.

During each rest "lap", each subject participated in a marksmanship skill test while wearing MOPP-0 or MOPP-1 protection (Section IID2.3). There was no marksmanship testing in MOPP-4. On that day, the subject starts were not staggered. All eight subjects started the march at the same time in MOPP-4. Comprehensive meteorological measurements were made at the track during all tests (Section II.F) and simultaneous meteorological measurements were made at McGregor range to support the thermal features aspect of the study (Section II.F.1.2). Table 2 summarizes the significant features of the outdoor test design.

Table II-2. Essential features of the approach march test design

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a) march on level quarter-mile track, walk four laps, rest 6 minutes and repeat a maximum of 12 miles (6 hr)
b) pre-hydrate prior to testing by consuming 250 ml of water, during the testing additional water intake was ad libitum, unless additional intake was directed by the testing staff (recorded)
c) pre- and post-exercise nude and clothed weights
d) heart rate, rectal temperature, surface skin temperatures
e) marksmanship tests: pre-test and test every 30 minutes (except MOPP-4)
f) on-site meteorological measurements

II.D.2.4 Physiological Performance Monitoring. The basic physiological performance data collected during the testing consisted of total marching time, rectal temperature, heart rate and skin temperature, pre- and post-test clothed and nude weights. Each subject's total exposure time was measured from the beginning of the first cycle until the subject completed the 12 mile march or was removed from testing for that day due to voluntary withdrawal, exceeding physiological limits, injury (blisters, etc) or heat strain symptoms (removal by test observer or medical monitor).

Rectal temperature was continuously recorded and stored on individual dataloggers with the rectal probe inserted 10 cm past the anal sphincter. Each digital datalogger display was systematically monitored by test observers. Electrodes for measuring heart rate were placed in the CM5 configuration and three local skin temperatures were also recorded. Total water intake was monitored as described in Section IID2.3. Gross water loss was determined by comparing pre- and post-test nude weights and then adjusting for water intake. Evaporative water loss was estimated from gross water loss and the increase in clothing weight due to absorbed sweat.

The dataloggers (Grant SQ32-2YS/8YS/1C/HR, Grant Instruments, Cambridge, UK) allowed the use of one "hard-wired" device to measure and record rectal temperature, skin surface temperatures and heart rate. Because an objective of the study was to obtain physiological field data comparable to data obtained with laboratory instrumentation for the purpose of evaluating the USARIEM heat strain model and comparison to laboratory measurements, it was critical that reliable rectal temperature readings were recorded throughout the study's duration. Rectal temperature probes measure core temperature at a single, fixed site regardless of the duration of the study. Despite objections summarized by Posen, et al. (1986), rectal temperature has been used in numerous studies, including P^2NBC^2 studies (Posen, et al. ,1986; Mitchell, et al., 1987; Knox, et al., 1987; Glumm, 1988; Knox, et al., 1989). A key reason for utilizing rectal temperature to measure core temperature is that the USARIEM Heat Strain Model is based on rectal temperature data (Pandolf, et al., 1986).

<u>II.D.2.5 Marksmanship Performance Monitoring.</u> During all test scenarios except MOPP-4, subjects were tested every four laps (during the break from marching) on a marksmanship task using either the NOPTEL ST-1000 marksmanship simulator (day) or an arm-hand steadiness test (night). The NOPTEL uses a laser transmitter attached to a de-militarized M-16 rifle to monitor aiming and firing accuracy. A variety of investigations have shown this task to be a reliable, high-fidelity simulation of military rifle marksmanship that is sensitive to a variety of environmental and operational stressors (Tharion, et al., 1992). No fine motor tasks were assessed during the MOPP-4 march.

Marksmanship testing began at the start point prior to the initial walk session. Subsequently, subjects were tested each time they completed four laps. During the 6 min "rest" period arm-hand steadiness or marksmanship data were collected. Following physiological instrumentation checks and water refills, subjects resumed their walk for another four laps. Subjects were tested every 30 minutes until they completed the 12 mile march or were withdrawn for either voluntary or medical reasons.

Each marksmanship test consisted of five shots. Subjects were instructed to shoot as quickly as possible without sacrificing accuracy, (i.e. both speed and accuracy were important). A verbal ready signal was given and, after a randomly-varied 1 to 10 second delay period subjects were signalled to shoot by the illumination of a red light positioned eight cm to the left of the target. Subjects shot from a free-standing unsupported position at a 2.3 cm diameter circular target 5 m away, simulating a 46 cm diameter target at 100 m, which is similar to the standard 49 cm wide, 100 m military silhouette man.

A computer program developed for digitizing shot records was used to convert scores to actual shot distances from the target center. Values reported are 20 times smaller than those obtained with a life-sized target at a 100 m distance on an actual shooting range. The X and Y-coordinates for the set of five shots derived from the computer program were entered into a data file and the following marksmanship parameters were calculated: distance from center of mass (DCM), shot group tightness (SGT), horizontal shot group tightness (HSGT), vertical shot group tightness (VSGT), horizontal deviation (HDEV), vertical deviation (VDEV) and sighting time. A complete description of how the measurements were obtained has been published previously (Tharion, et al., 1992).

The arm-hand steadiness test used a modified Gardner Steadiness Tester (Lafayette Instrument Company, Lafayette, IN) to evaluate aiming steadiness. The volunteer was required to stand with his dominant hand and arm extended out to his side and parallel to the ground. While in this position, he was required to insert a hand-held metal stylus (2 mm in diameter) into a small round hole (4 mm in diameter) in a metal plate positioned at eye height and attempt to hold it there for one full minute without touching the sides of the hole. The stylus was attached to a pistol grip handle and the subject held it in the same manner that he would hold and aim a pistol. The volunteers's score was the total amount of "time on-target" (i.e. the total amount of time the stylus did not touch the sides of the hole) (Kobrick et al., 1988).

II.E. CLOTHING SYSTEM AND "FIGHTING LOAD"

Mission Oriented Protective Posture (MOPP) level indicates the level of chemical protective (CP) clothing worn (STP21-1-SMCT, 1985; Hess and Russell, 1988). In MOPP-0, the subjects wore a lightweight BDU with no chemical protection. In MOPP-1, they wore the overgarment zipped closed over the BDU, but not the mask, hood, gloves or overboots. In both MOPP-0 and MOPP-1, subjects carried the CP clothing which was not worn as part of their "fighting load." In MOPP-4, the subjects wore the complete chemical protective ensemble, including mask, hood, gloves and overboots over underwear and carried their BDU's. The fighting load consists of items selected from the official "combat load" which are considered essential "to complete the immediate mission" (Inghram, 1987). Our subjects carried a 22 kg "fighting load", the combat load weight recommended by the US Infantry school, (Knapik, 1989). All subjects carried the same load, which is the total of all clothing and equipment, regardless of what proportion is carried or worn. The weight of the datalogger was substituted for some equipment and sand weights were substituted for live munitions, bayonet, entrenching tool and poncho. All subjects wore pistol belt, framed backpack, PASGT helmet and carried a deactivated training rifle. Table 3 lists all the equipment worn or carried and their approximate weights. Due to differences in clothing weights, actual subject loads varied slightly, with a mean load of 22.3 kg.

Table II-3. Subject combat load (BDM, 1986, 1987; Knapik, 1989 and personal communication) in kilograms

item	est. weight
M16A1 training rifle	3.2 kg
1 canteen, cup and cover with water	1.4 kg
pistol belt	0.3 kg
CP BDO	2.7 kg
CP mask and hood	1.4 kg
CP boots	0.4 kg
CP glove set	0.2 kg
sunglasses, lip salve, watch, sun lotion	0.5 kg
flashlight	0.4 kg
underwear	0.3 kg
cushion sole socks	0.1 kg
combat boots	1.9 kg
combat pack	2.8 kg
lightweight BDU	1.3 kg
PASGT helmet	1.5 kg
datalogger	0.9 kg
sand	2.7 kg
total	22.0 kg

II.F. ENVIRONMENTAL MONITORING

A portable weather station was located at the primary site, the test track, in the Logan Heights section of Fort Bliss. This battery operated system logged local air and ground temperatures, dew point, wind speed, and solar radiation parameters at 1 minute intervals. Supplementary environmental heat stress measurements were also made using portable Wet Bulb Globe Temperature (WBGT) dataloggers. These battery operated devices logged air temperature, natural wet bulb temperature, black globe temperature and the computed WBGT index, at 1 minute intervals.

II.F.1 Meteorological Data Station at Logan Heights

II.F.1.1 System Description. The station consisted of two battery powered data loggers (Campbell CR-7 and 21X, Campbell Scientific, Logan, UT), a tripod to support the air temperature thermometers, black globe thermometer and barometer and three pole mounts for cup anemometers, net radiometers and two humidity sensors. Pyranometers were placed near the tripod and dataloggers. Three thermocouples and one thermistor were used to measure ground or surface temperatures. A detailed explanation of the basis for the measurements and instrumentation of the field meteorological station used for this study may be found in Santee and Gonzalez (1988). The instruments were set-up and taken down each day, although the mounts were left in place.

II.F.1.2 Temperature. Shielded copper-constantan (Type T) thermocouples were suspended from an arm of the support tripod at heights of 2, 1.5, 1 and 0.5 m. Four additional unshielded thermocouples were attached to the humidity sensor probes. A thermistor probe (107B, Campbell Scientific, Logan, UT) was placed 5 cm into the loose soil to measure ground temperature. A thermocouple thermometer was placed inside a Vernon black globe (6 inch diameter) suspended at 1.2 m (4 ft). The surface temperature of the track was measured by taping two thermocouple thermometers to the track surface with silver colored duct tape.

II.F.1.3 Radiation. Black globe temperature is a simultaneous measurement of the interaction of radiation and convective heat loss (wind) measured as a temperature. Radiation was measured directly with two types of radiometers; pyranometers which measure solar radiation and net radiometers which measure solar and thermal (IR) radiation. Two pyranometers (Eppley PSP and M8-48, Eppley Laboratory, Newport, RI) were used to measure global radiation.

The pyranometers were placed on a 1.2 x 1.2 m (4 x 4 ft) sheet of plywood and leveled. The surrounding vegetation was of insufficient height to shade the instruments. A third pyranometer (PSP as above) was mounted on a shadowband (Eppley Laboratory, Newport, RI) to measure indirect solar radiation. The M8-48 pyranometer was a back-up instrument; all reported solar radiation values were measured with the PSP pyranometers. A shadowband is a u-shaped band or hoop of metal which is angled in a southern direction to block direct sunlight from reaching the sensor. The angle is adjusted for the daily declination and latitude to match the path of the sun from east to west. The shadowband was raised on wooden blocks so that angle adjustments to the shadowband could be made.

Direct and diffuse solar radiation values were calculated from the measured values for global and shaded (diffuse) solar radiation. The value measured with the shaded pyranometer is corrected for the effects of the shadowband blocking a small amount of diffuse radiation to obtain the diffuse radiation value. Diffuse radiation is then subtracted from the global radiation value to obtain an uncorrected direct radiation value. Direct solar radiation is then corrected for the zenith angle to obtain an energy flux for the direct solar beam. Reflected solar radiation was estimated from global radiation by using an approximate albedo of 0.25.

Two Fritschen type net radiometers (Radiation Energy Balance Systems, Seattle, WA) were used in conjunction with the pyranometers to measure incoming sky and ground thermal radiation. Net radiometers measure the difference between sky and ground radiation in both visible and infrared spectrums. One net radiometer was fitted with a cup which blocks ground radiation (Idso, 1970; Coulson, 1975).

Calculation of thermal radiation values from instrument measurement was dependent on having data from four instruments. When complete data sets were not available, thermal radiation values were calculated using ground temperature and the Stephan-Boltzmann equation for ground thermal radiation and the Swinbank equation (Swinbank, 1963; Sellers, 1965, Montieth, 1973) with air temperature for sky thermal radiation.

II.F.1.4 Wind Speed. Three cup anemometers were used to measure wind speed. Two anemometers (M 12102D, R.M. Young Co, Traverse City, MI) were mounted on the top of iron pipes at 1.5 and 2 m. The third (014A Met-One Wind Speed Sensor, Campbell Scientific, Logan, UT) was side mounted at 1.5 m. The Met-one anemometer was used as a back-up instrument: all reported wind speeds were measured with the Young anemometers.

II.F.1.5 Humidity. Two humidity probes (HMP 36, Vaisala Inc, Helsinki, Finland) were mounted at 1 m on the same pole as a cup anemometer. The signal from the probe were read directly into a Campbell 21X datalogger rather than a signal translation box. Two thermocouple thermometers were attached to each probe to measure air temperature for that sensor.

II.F.1.6 Barometric Pressure. An analog output barometer (M 7105-A, WeatherMeasure Weathertronics, Sacramento, CA) was mounted above the base of the tripod (1 m) to measure barometric pressure.

II.F.2 Thermal Feature Investigation

The ability to assess the severity of heat stress conditions on a spatial and temporal scale relevant to military operations is essential for identifying significant thermal features. The WBGT index and its components, wet bulb, dry bulb, and black globe temperatures, represent a substantial compromise relative to the discrete environmental measurements obtained from the portable weather station located at the track site. Nevertheless, the historical importance of WBGT in military heat stress management, it's direct relevance to previous work with satellite data, and the ready availability of a number of WBGT dataloggers, made it a reasonable choice for the thermal features investigation. Battery operated Metrosonics model hs-371 WBGT dataloggers were used to assess the diurnal and point to point variability in heat stress conditions. All WBGT measurements were made at a sensor height of 1.3 meters

above ground level. The onboard real time clocks of all 8 loggers were synchronized to within ± 15 seconds. WBGT data were recorded at 1 minute intervals at the primary test site at Logan Heights, Fort Bliss and also at McGregor Range, approximately 35 km to the Northeast. For consistency with existing WBGT heat injury prevention guidance (TB MED 507, FM 21-10), WBGT values are presented in the Fahrenheit temperature scale.

<u>II.F.2.1 The Track at Logan Heights.</u> Three data loggers were deployed at the Logan Heights track: two on the natural surface approximately 3 meters inside the North and South ends of the track oval, and one on the paved track surface itself, at the mid point of the Western leg. These loggers were programmed for operation primarily during human data collection periods. In the satellite data analysis, since the logger separation is well below the 1.1 km spatial resolution limit for AVHRR, data for the three loggers will be averaged together and georeferenced to the track centroid located at Latitude N 31° 50.6', Longitude W 106° 26.4'. The track surface is approximately 1,205 meters above sea level.

<u>II.F.2.2 Secondary Sites at McGregor Range.</u> A total of 5 dataloggers were initially deployed on 12 August across a 40 km^2 area at McGregor Range. These loggers were programmed for 24 hour operation. The range is essentially flat, uniformly vegetated desert (1-2 meter height), and the surface elevation is approximately 1240 meters above sea level. Logger separation (nearest neighbor) at McGregor Range averaged 4.35 km (2.7 miles). Because daylight NOAA satellite overpasses occurred in the morning and afternoon hours, the downloading of data from the loggers was scheduled for noontime when the brief interruption in logged WBGT data would be least intrusive on subsequent analyses. The 24 hour data collection periods at McGregor Range therefore began at noon time and ended at approximately noontime the next day. One of the 5 loggers was permanently disabled during a thunderstorm on 14 August, and the remaining loggers were re-deployed, eliminating site number 5 after that date.

Table II-4. Logger locations at McGregor Range

Site	Distance from Track (km)	Latitude	Longitude
1	35.7	N 32° 04.9'	W 106° 11.2'
2	33.3	N 32° 04.9'	W 106° 13.6'
3	30.9	N 32° 04.9'	W 106° 16.3'
4	39.0	N 32° 08.2'	W 106° 14.2'
5	37.8	N 32° 06.9'	W 106° 10.9'

II.F.3 Satellite Data

Satellite data were obtained from three National Oceanographic and Atmospheric Administration (NOAA) polar orbiting weather satellites, NOAA-10, NOAA-11, and NOAA-12. The High Resolution Picture Transmition (HRPT) images from a total of 32 satellite passes over Fort Bliss during the test period were recorded on Digital Audio Tape (DAT) by SeaSpace of San Diego, California. These tapes contain data from the Advanced Very High Resolution Radiometer (AVHRR) and the TIROS Operational Vertical Sounder (TOVS). Data from these instruments are needed to estimate the ground level heat stress/WBGT parameters using preliminary algorithms developed under MRDC/USARIEM contract No. DAMD17-86-C-6004 (Schatzle et al., 1989). Appendix A provides a table listing satellite data file identifications, overpass times, and contemporary ground truth data records.

II.G. HEAT STRAIN PREDICTION MODEL

Environmental and body temperature (T_{re}) data obtained at the primary site were used in a preliminary evaluation of the performance of the P^2NBC^2 Heat Strain

Decision Aid implementation of the USARIEM Heat Strain Model, v1.0. The environmental inputs for the modeling runs were obtained by dividing the nominal six hour sessions into a series of contiguous 30 minute blocks, or periods, and then computing the average air temperature, humidity, and wind speed values for each block. The T_{re} predictions were based on the following inputs: 30 minute averages of the 1 minute interval environmental data, menu selected MOPP-0, MOPP-1, or MOPP-4 clothing parameters, average subject height of 177 cm, average body weight of 80.5 kg, six days of heat acclimation, no dehydration, and a menu selected metabolic rate for the closest listed task: "walking on a hard surface at 1 m/s with a 20 kg load". Solar radiation inputs to the model were limited to either the "full sun" or "at night" categories. The software was modified to allow input of a starting T_{re} for each 30 minute period. All predictions were based on an assumed initial starting T_{re} of 37°C for the first 30 minute period. When the weather inputs were updated for each subsequent period, the final output T_{re} value from the previous 30 minute time period was input as a starting temperature for the new period. The average measured T_{re} for all volunteers marching in the same uniform ensemble was then computed for each minute and compared with the predicted T_{re} for that minute. Prediction error for each sampled minute was computed as predicted T_{re} minus the average measured T_{re}. Because the number of volunteers marching in a particular MOPP ensemble was subject to attrition with time, there was a progressive reduction in the "n" used to compute the average T_{re}. When only one subject remained on the track, his T_{re} was used to compute the error for the predicted value. This evaluation is not intended to duplicate far more rigorous and comprehensive analytical efforts currently underway as part of the P^2NBC^2 model validation program.

III. RESULTS

III.A. DESCRIPTIVE SUBJECT PARAMETERS

Table III-1 presents the general subject parameters of height, weight, age and percent body fat. The mean value for the Dubois surface area (Dubois and Dubois, 1916) for eight subjects was (1.97 ± 0.17 m^2). Peak $\dot{V}O_2max$ values and metabolic rates are presented in Table III-2.

Table III-1. Subject parameters

Subject	Age (yr)	Height (cm)	Weight (kg)	Body Fat (%)
1A	20	168	70.6	16.5
1B	19	174	66.2	9.4*
2A	23	170	73.2	17.8
2B	22	185	76.0	16.7
3A	19	172	79.1	15.0*
3B	19	179	78.2	12.7
4A	22	192	101.1	21.9
4B	28	177	99.5	17.2
9**	20	175	90.8	24.4
mean	22	177	80.5	15.9
s.d.	3	8	12.1	3.5
n	8	8	8	8

* skinfold, not hydrostatic weighing
** subject 3B in night 1, not included in mean calculations

Table III-2. Subject peak $\dot{V}O_2max$ and metabolic rates

Subject	$\dot{V}O_2max$ ($ml \cdot kg^{-1} \cdot min^{-1}$)	Metabolic rate (W) no pack	Metabolic rate (W) pack
1A	59.2	288	320
1B	65.9	289	333
2A	53.6	334	380
2B	47.8	301	350
3A	51.3	343	416
3B	48.7	321	363
4A	51.4	432	531
4B	46.6	336	389
9*	N.A.	336	389
mean	53.1	331	391
s.d.	6.1	43	61
n	8	8	8

*subject 9 not included in mean calculations

III.B. PHYSIOLOGICAL RESPONSES

III.B.1 Rectal Temperature

Tables III-3 and 4 present data for the change in rectal temperature ($\Delta T_{re} \cdot hr^{-1}$ in $°C \cdot hr^{-1}$). The change in rectal temperature was calculated from the difference between a subject's rectal temperature 10 minutes into the first walking session and his final rectal temperature. A delay of ten minutes allows the subject to reach a metabolic steady state and reduces any confounding influence associated with the initial start time (t=0). Table III-5 summarizes the $\Delta T_{re} \cdot hr^{-1}$ by MOPP level and treatment (day or night), without an adjustment for differences between test sessions. Figures III-1 through 5 present ten plots of T_{re} (all subjects x day x uniform). Rectal temperature data will be located in the Soldier Performance Database under preparation at USARIEM for the P^2NBC^2 program.

Table III-3. Change in rectal temperature for subjects in MOPP-0 and MOPP-1 under night conditions

A. 13 August 1992

MOPP-0 Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re} \cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1A	37.69	37.57	344	.02	.12
2A	37.82	37.22	344	.11	.60
3A	37.65	37.24	344	.07	.41
4A	37.24	37.36	344	-.02	-.12

MOPP-1 Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re} \cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1B	37.27	37.09	344	.03	.18
2B	37.47	37.35	344	.02	.12
#9	37.64	37.70	244	-.02	-.06
4B	37.27	37.24	344	.01	.03

B. 20 August 1992

MOPP-1 Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re} \cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1A	37.75	37.75	224	.00	.00
2A	37.58	37.22	235	.09	.36
3A	37.36	37.29	196	.02	.07
4A	37.60	37.60	8	.00	.00

MOPP-0 Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re} \cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1B	37.12	37.21	258	-.02	-.09
2B	37.29	37.35	135	-.03	-.06
3B	37.46	37.10	76	.28	.36
4B	37.29	37.24	152	.02	.05

Table III-4. Change in rectal temperature for subjects in MOPP-0, MOPP-1, and MOPP-4 during daylight hours

A. 16 August 1992

MOPP-1

Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$T_{re}\cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1A	...	...	...	...	...
2A	38.95	37.39	146	.64	1.56
3A	38.48	37.34	159	.43	1.14
4A	38.50	37.11	153	.55	1.39

MOPP-0

Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re}\cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1B	37.60	37.27	342	.06	.33
2B	37.89	37.47	259	.10	.42
3B	37.70	37.22	169	.17	.48
4B	37.06	37.00	37	.10	.06

B. 17 August 1992

MOPP-0

Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re}\cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1A	38.32	37.63	344	.12	.69
2A	37.88	37.16	344	.13	.72
3A	37.63	37.11	344	.09	.52
4B	37.65	36.94	343	.12	.71

MOPP-1

Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re}\cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1B	38.05	36.97	331	.20	1.08
2B	38.19	37.26	278	.20	.93
3B	...	...	...	...	...
4B	...	...	...	...	...

18 August 1992

MOPP-4

Subject	Final T_{re} (°C)	T_{re} (10 min) (°C)	time (min)	$\Delta T_{re}\cdot hr^{-1}$ (°C·hr^{-1})	ΔT_{re} (°C)
1A	37.99	37.54	92	.29	.45
2A	38.42	37.28	132	.52	1.14
3A	38.50	37.29	191	.38	1.21
4A	37.47	37.29	86	.13	.18
1B	37.33	37.27	62	.06	.06
2B	37.65	37.47	63	.17	.18
3B	37.94	37.55	110	.21	.39
4B	38.26	37.29	164	.35	.97

Table III-5. Change in rectal temperature ($\Delta T_{re} \cdot hr^{-1}$) by uniform and treatment

	NIGHT		DAY		
Subject	MOPP-0	MOPP-1	MOPP-0	MOPP-1	MOPP-4
1A	.02	.00	.12	---	.29
1B	-.0[illegible]	.03	.06	.20	.06
2A	.1	.09	.13	.64	.52
2B	-.03	.02	.10	.20	.17
3A	.07	.02	.09	.43	.38
3B	.28	-.02*	.17	---	.21
4A	-.02	.00**	.12	.55	.13
4B	.02	.01	.10**	---	.36
mean	.05	.02	.11	.40	.26
s.d.	.10	.03	.03	.18	.14
(n)	(8)	(7)	(7)	(5)	(8)

* subject 9
** subject not included in calculated mean

Figure III-1 Rectal temperatures 13 August 91 Night Test (MOPP-0 and MOPP-1)

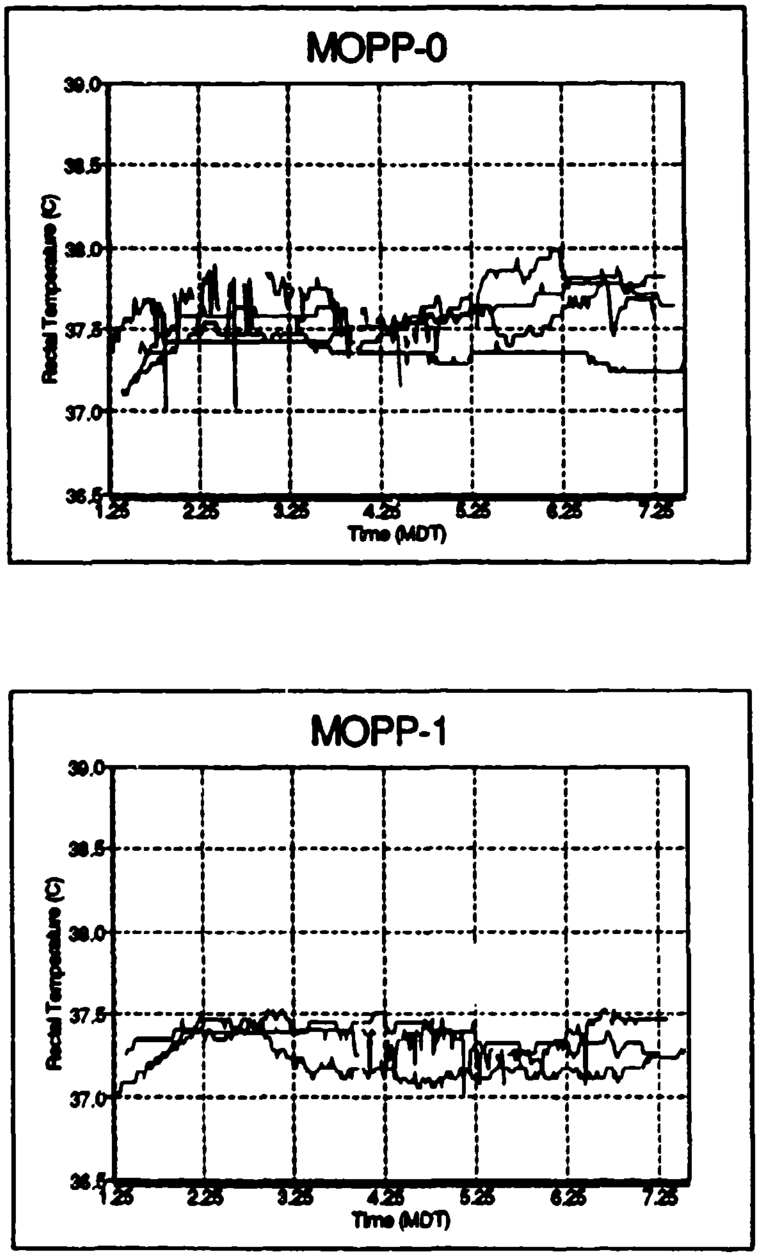
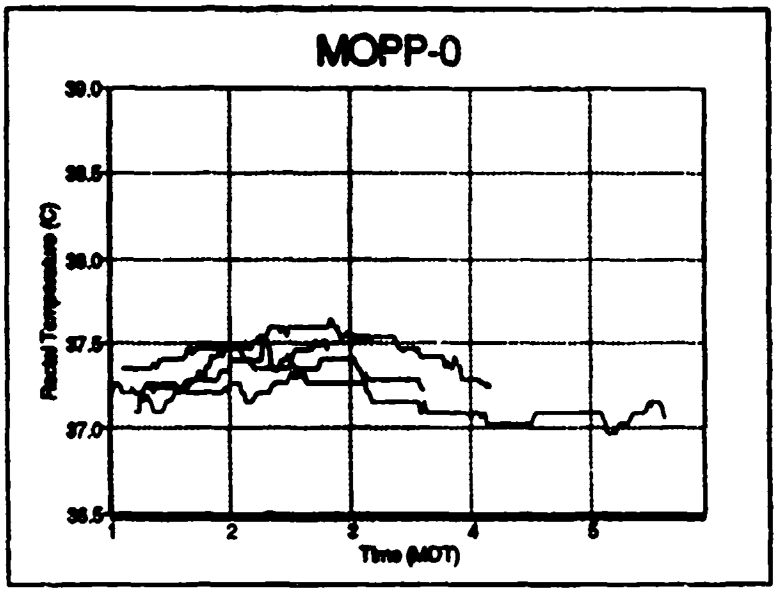


Figure III-2 Rectal temperatures 20 August 91 Night Test (MOPP-0 and MOPP-1)



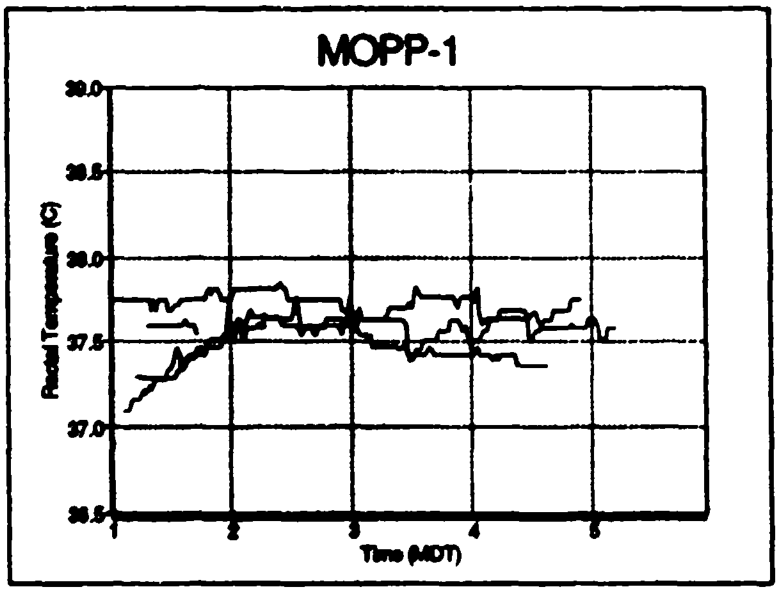
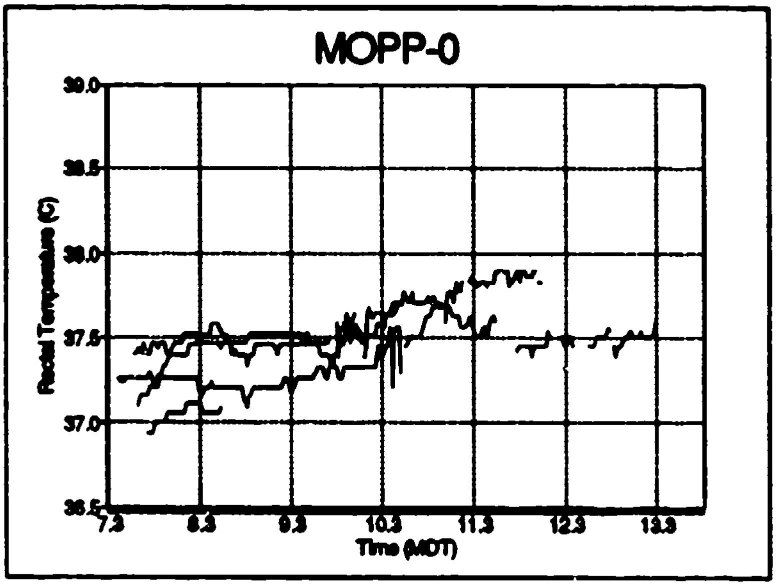


Figure III-3 Rectal temperatures 16 August 91 Day Test (MOPP-0 and MOPP-1)



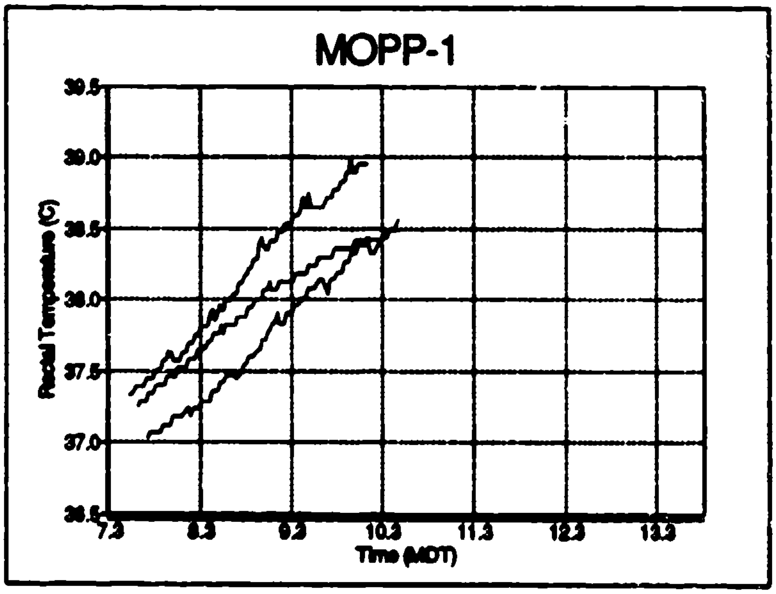
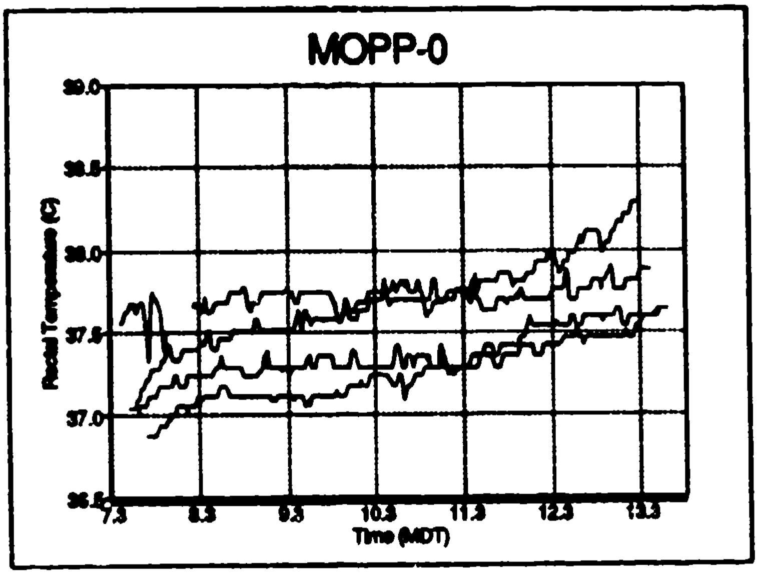


Figure III-4 Rectal temperatures 17 August 91 Day Test (MOPP-0 and MOPP-1)



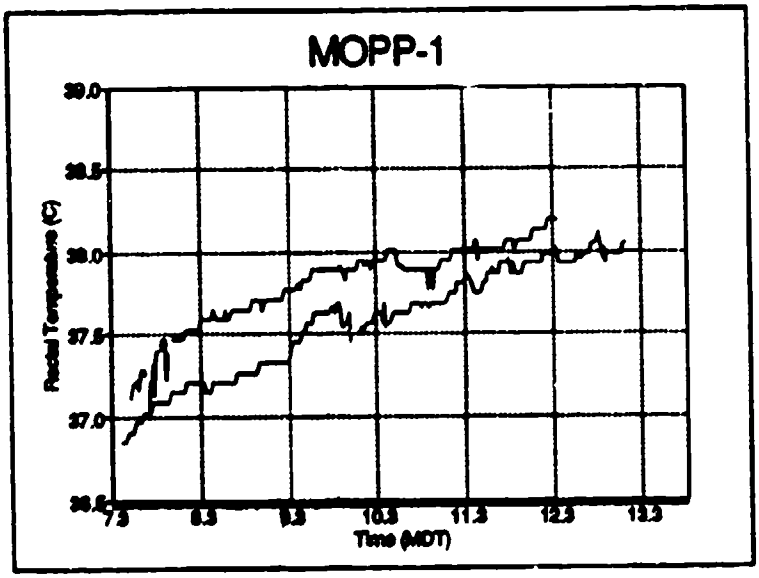
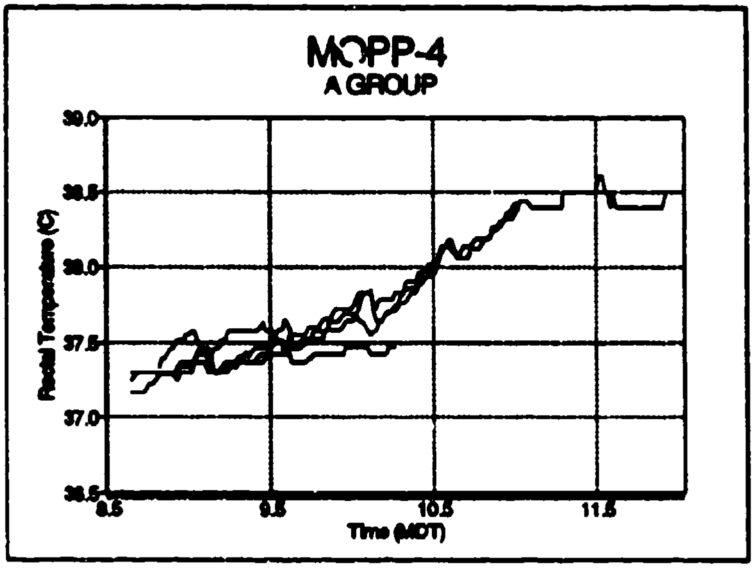


Figure III-5 Rectal temperatures 18 August 91 Day Test (MOPP-4 by group)



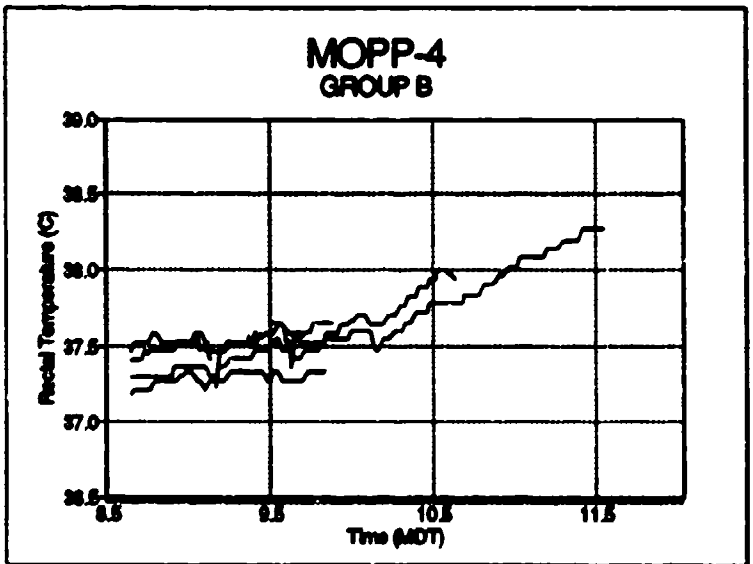


Figure 10

III.B.2 Skin Temperatures

Table III-6 presents the initial, final and change in mean skin temperature ($\bar{T}_{sk}$) (subject x day). Figure III-6 presents sample plots of skin and rectal temperature for selected subjects during night (20 August 91) and day (17 and 18 August 91) tests. All available data will be located in the Soldier Performance Database.

The data for the mean skin temperature ($\bar{T}_{sk}$) are presented only to provide an indication of the general data trends. As noted in the methods section, $\bar{T}_{sk}$ is the weighted sum of three separate measurements. An invalid or missing value for one of the three measurement sites precludes the calculation of a $\bar{T}_{sk}$ value. Collection sites were frequently lost due to mechanical loosening of the sensor. The number of subjects for which $\bar{T}_{sk}$ data was available on a given test day varied from a high of seven out of eight to a low of three of six subjects. During a sustained walk, the probability that a measurement site will be lost increases relative to shorter term chamber studies. For subjects with data, the data collection period is generally shorter than the total participation time.

In addition to the problems associated with data collection, neither minimum nor maximum values necessarily occurred during the initial or terminal period. Some subjects may have achieved a stable pattern of variation (walk vs. rest, etc.) whereas the onset of sweating and or changes in thermal parameters caused a shift from maximum or minimum values. Examination of individual plots for both $\bar{T}_{sk}$ and the three T_{sk} sites will probably be more valuable than attempting to make statistical inferences from summary tables.

Despite the lengthy qualifications regarding the data, Table III-6 does indicate general trends. Except where noted, the values presented are means for the initial and terminal 10 minutes of data, rather than reporting just the initial and final values. During the two night tests, out of 11 data sets, in 9 cases $\bar{T}_{sk}$ values decreased between initial and terminal periods For MOPP-0 vs. MOPP-1, $\bar{T}_{sk}$ decreased in 5 of 5 cases, and for MOPP-1 $\bar{T}_{sk}$ decreased 4 of 6 cases. During the day tests, 11 out

of 13 data sets had an increase in mean skin values; 3 of 4 for MOPP-0, 4 of 4 for MOPP-1 and 4 of 5 for MOPP-4. In several cases, the short period of separation between initial and terminal periods and the variability within the 10 minute samples would preclude any parametric statistical significance.

Table III-6. Final mean skin temperatures ($\bar{T}_{sk}$)

Table 6a Night 1

	1A	2A	3A	4A	1B	2B	#9	4B
initial	32.4	32.4	32.2	32.4	na	33.5	33.7	32.7
final	30.5	30.5	30.0	29.7	na	34.4	33.2	31.7
$\Delta\bar{T}_{sk}$	-1.9	-1.9	-2.2	-2.7	na	+0.9	-0.5	-1.0
uniform	M-0	M-0	M-0	M-0	na	M-1	M-1	M-1

Table 6b Night 1

	1A	2A	3A	4A	1B	2B	3B	4B
initial	33.9	31.7	35.6	na	na	33.1	na	na
final	32.9	31.8	34.3	na	na	32.1	na	na
$\Delta\bar{T}_{sk}$	-1.0	+0.1	-1.3	na	na	-1.0	na	na
uniform	M-1	M-1	M-1	na	na	M-0	na	na

Table 6c Day 1

	1A	2A	3A	4A	1B	2B	3B	4B
initial	na	34.3*	34.3	34.5	na	32.7	na	34.5
final	na	34.5*	35.6	35.4**	na	35.3	na	35.1
$\Delta\bar{T}_{sk}$	na	+0.2	+1.3	+0.9	na	+2.6	na	+0.6
uniform	na	M-1	M-1	M-1	na	M-0	M-0	M-0

Table 6d Day 2

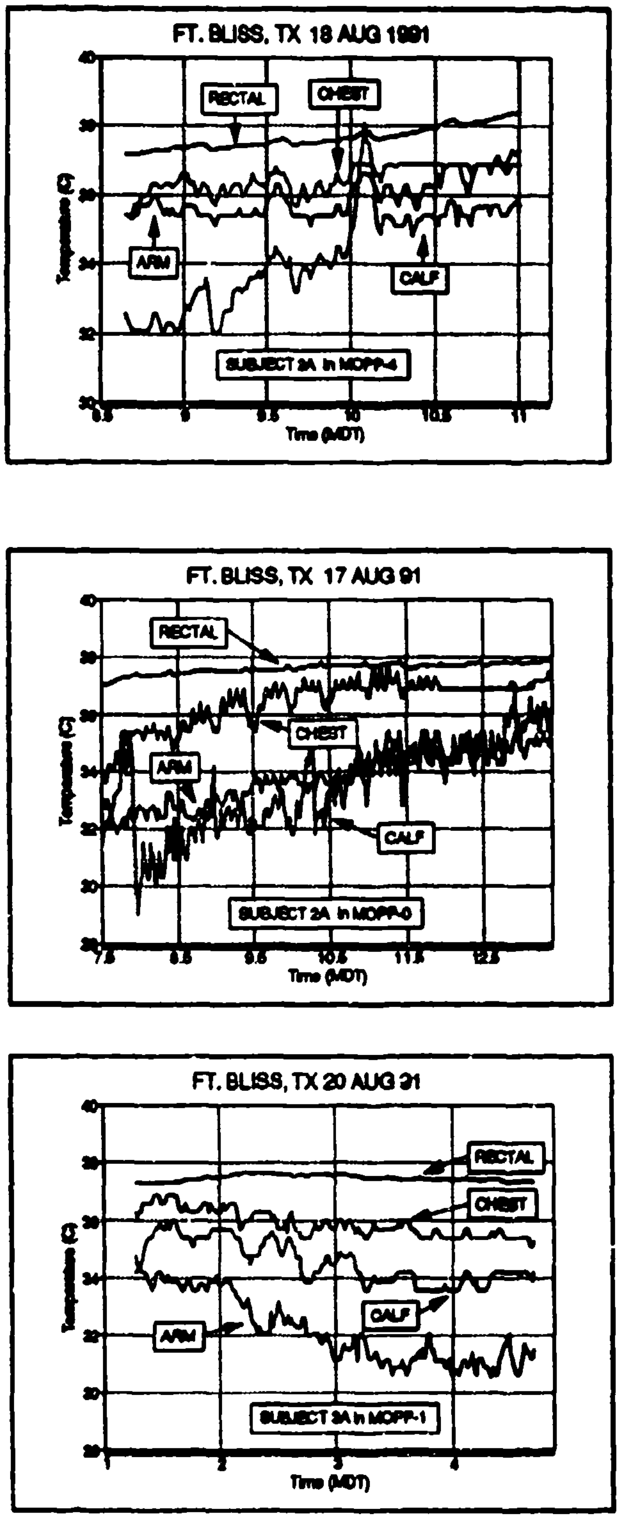
	1A	2A	3A	4A	1B	2B	3B	4B
initial	32.7	33.2	na	na	na	33.4	na	na
final	32.4	36.4	na	na	na	35.8	na	na
$\Delta\bar{T}_{sk}$	-0.3	+3.2	na	na	na	+2.4	na	na
uniform	M-0	M-0	na	na	na	M-1	na	na

Table 6e Day 3

	1A	2A	3A	4A	1B	2B	3B	4B
initial	33.7	34.5	34.7	34.4	na	35.7	na	na
final	35.1	36.5	36.5	35.5***	na	35.0	na	na
$\Delta\bar{T}_{sk}$	+1.4	+2.0	+1.8	+1.1	na	-0.7	na	na
uniform	M-4	M-4	M-4	M-4	na	M-4	na	na

* mean for 5 minutes, total separation 10 minutes
** mean for 9 values, one missing value in 10 minutes
*** mean for 6 minutes

Figure III-6. Representative skin and rectal temperature plots



III.B.3 Heart Rate

Table III-7 presents final heart rate data (subject x day). Table III-8 presents the maximum heart rate data (subject x day x uniform). Figure III-7 presents samples plots of selected subjects for night (13 August 91) and day (17 August 91) test runs. Final heart rate was selected as the highest value recorded in the last nine minutes. The maximum heart rate is the highest value in the record. The hand recorded (6 min interval) heart rate data will be located in the Soldier Performance Database.

Table III-7. Final heart rate data for subject x day

Table 7a Night 1

subject	MOPP-0	MOPP-1
1A	106	...
1B	...	98
2A	124	...
2B	...	104
3A	101	...
#9	...	141
4A	98	...
4B	...	104

Table 7b Night 2

subject	MOPP-0	MOPP-1
1A	...	113
1B	101	...
2A	...	131
2B	105	...
3A	...	121
3B	94	...
4A	...	108
4B	99	...

Table 7c Day 1

subject	MOPP-0	MOPP-1
1A	...	...
1B	123	...
2A	...	159
2B	119	...
3A	...	173
3B	109	...
4A	...	143
4B	97	...
	...	

Table 7d Day 2

subject	MOPP-0	MOPP-1
1A	144	...
1B	...	146
2A	149	...
2B	...	126
3A	143	...
3B	...	...
4A	113	...
4B	...	

Table 7e Day 3

subject	MOPP-4
1A	139
1B	112
2A	166
2B	115
3A	174
3B	119
4A	108
4B	142

Table III-8. Maximum heart rate data for subject x uniform x day

Table 8a Night 1

subject	MOPP-0	MOPP-1
1A	112	...
1B	...	128
2A	130	...
2B	...	108
3A	129	...
#9	...	141
4A	123	...
4B	...	111

Table 8b Night 2

subject	MOPP-0	MOPP-1
1A	...	115
1B	108	...
2A	...	131
2B	112	...
3A	...	121
3B	100	...
4A	...	108
4B	110	...

Table 8c Day 1

subject	MOPP-0	MOPP-1
1A	...	...
1B	140	...
2A	...	164
2B	119	...
3A	...	175
3B	110	...
4A	...	150
4B	97	...

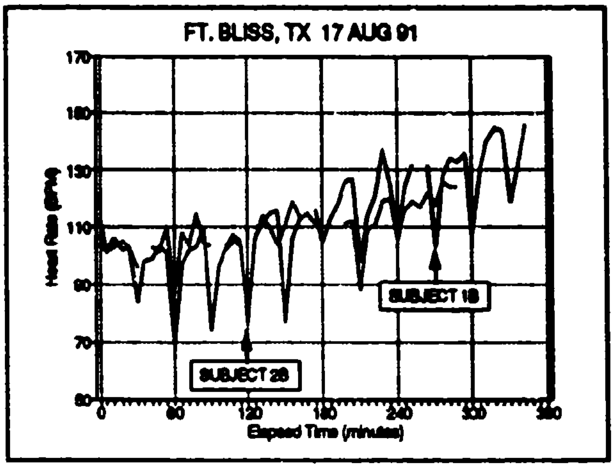
Table 8d Day 2

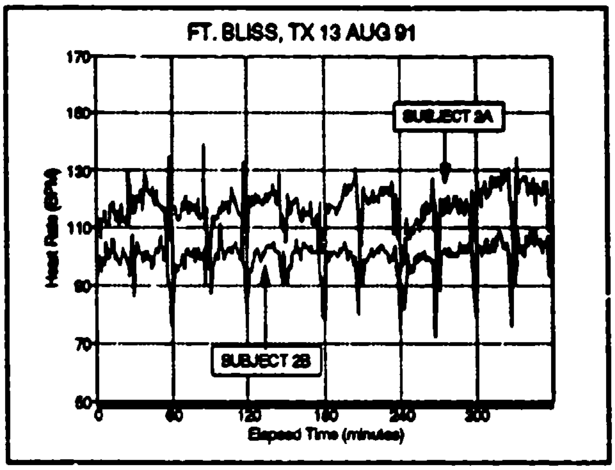
subject	MOPP-0	MOPP-1
1A	144	...
1B	...	146
2A	149	...
2B	...	126
3A	143	...
3B	...	...
4A	116	...
4B	...	...

Table 8e Day 3

subject	MOPP-4
1A	145
1B	115
2A	166
2B	118
3A	174
3B	119
4A	123
4B	142

Figure III-7. Representative heart rate plots





III.B.4 Water consumption

Each individual's total water consumption is reported in Table III-9 (subject x day x uniform). Table III-10 presents data for total weight loss (subject x day x uniform). These values represent the actual body water loss, not the effective sweat rate. Average water loss for the night test on 13 August for subjects in MOPP-0 was 0.071 $gm \cdot min^{-1} \cdot kg^{-1}$ whereas subjects in MOPP-1 lost 0.104 $gm \cdot min^{-1} \cdot kg^{-1}$. During the daylight tests, subjects in MOPP-4 lost water at a rate (0.186 $gm \cdot min^{-1} \cdot kg^{-1}$) which was intermediate between MOPP-0 (0.158 $gm \cdot min^{-1} \cdot kg^{-1}$) and MOPP-1 (0.248 $gm \cdot min^{-1} \cdot kg^{-1}$). The values for daylight MOPP-0 and MOPP-1 are an average of 16 and 17 August. These data should not be compared without an adjustment for the differences in environmental conditions experienced by subjects during those daylight test days. The duration of exposure was also a confounding factor.

Table III-9. Water consumption (no time correction) liters per subject x uniform x day

Table 9a Night 1

subject	MOPP-0	MOPP-1
1A	1.3	...
1B	...	1.8
2A	1.1	...
2B	...	1.8
3A	1.8	...
#9	...	1.7
4A	2.7	...
4B	...	3.0

Table 9b Night 2

subject	MOPP-0	MOPP-1
1A	...	1.0
1B	1.4	...
2A	...	2.0
2B	0.7	...
3A	...	2.2
3B	1.0	...
4A	...	1.0
4B	0.5	...

Table 9c Day 1

subject	MOPP-0	MOPP-1
1A	...	...
1B	6.2	...
2A	...	3.1
2B	6.3	...
3A	...	4.0
3B	3.3	...
4A	...	5.6
4B	1.2	...

Table 9d Day 2

subject	MOPP-0	MOPP-1
1A	3.5	...
1B	...	5.8
2A	3.1	...
2B	...	4.2
3A	3.4	...
3B	...	...
4A	7.4	...
4B	...	...

Table 9e Day 3

subject	MOPP-4
1A	1.0
1B	1.1
2A	2.0
2B	1.6
3A	2.4
3B	3.3
4A	1.9
4B	2.4

Table III-10. Total body water loss gm·min^{-1}·kg^{-1} (body weight) for subject x uniform x day

Table 10a Night 1

subject	MOPP-0	MOPP-1
1A	0.078	.....
1B	.....	0.106
2A	0.076	.....
2B	.....	0.110
3A	0.092	.....
#9	.....	0.108
4A	>.036	.....
4B	.....	0.093

Table 10b Night 2

subject	MOPP-0	MOPP-1
1A	.....	0.124
1B	0.085	.....
2A	.....	0.122
2B	0.089	.....
3A	.....	0.151
3B	0.086	.....
4A	.....	0
4B	0.078	.....

Table 10c Day 1

subject	MOPP-0	MOPP-1
1A	.....	.....
1B	0.202	.....
2A	.....	0.183
2B	0.194	.....
3A	.....	0.377
3B	0.100	.....
4A	.....	0.205
4B	0.254	.....

Table 10d Day 2

subject	MOPP-0	MOPP-1
1A	0.135	.....
1B	.....	0.254
2A	0.130	.....
2B	.....	0.222
3A	0.154	.....
3B	.....	.....
4A	0.098	.....
4B	.....	.....

Table 10e Day 3

subject	MOPP-4
1A	0.219
1B	0.189
2A	0.152
2B	0.216
3A	0.199
3B	0.241
4A	0.021
4B	0.159

III.B.5 Endurance

Table III-11 presents "endurance", the length of participation time of a subject from the start to withdrawal or completion of a test session (subject x day x uniform). Table 11 presents the data by uniform and treatment. Only one subject in MOPP-1 was able to "complete" (terminated by medical monitor 1 lap from completion) the full 12 mile walk. Subjects who voluntarily ended participation did not reach the critical limit (39.5°C) for rectal temperature or maximum heart rate (180 BPM). On 18 August 91, two subjects withdrew due to adverse responses to the mask. One subject lasted 3 hours and 24 minutes in MOPP-4. The WBGT at the time of his withdrawal was 85°F. The final test session was the make-up night test session on 20 August 91 beginning at 0104 hrs. No subject completed the last night test session. The investigators felt that subject morale and/or cumulative fatigue adversely impacted this final test session.

Table III-11. Endurance time (minutes) for subject x uniform x day

Table 11a Night 1

subject	MOPP-0	MOPP-1
1A	354	...
1B	...	354
2A	354	...
2B	...	354
3A	354	...
#9	...	254*
4A	354	...
4B	...	354

Table 11b Night 2

subject	MOPP-0	MOPP-1
1A	...	234
1B	268	...
2A	...	245
2B	145	...
3A	...	206
3B	86	...
4A	...	18**
4B	162	...

Table 11c Day 1

subject	MOPP-0	MOPP-1
1A	...	...
1B	352	...
2A	...	156
2B	269	...
3A	...	169
3B	176	...
4A	...	163
4B	47**	...

Table 11d Day 2

subject	MOPP-0	MOPP-1
1A	354	...
1B	...	341
2A	354	...
2B	...	288
3A	354	...
3B	...	...
4A	353	...
4B	...	...

Table 11e Day 3

subject	MOPP-4
1A	102
1B	72
2A	142
2B	73
3A	201
3B	120
4A	96
4B	174

* subject 9

** subject withdrawn not due to physiological limitations

III.C. MARKSMANSHIP RESULTS

Marksmanship trials took place during the daylight test sessions as ambient temperatures increased. Distance from center of mass and SGT were shown to deteriorate while walking in MOPP-1 after 3.5 hrs or by the 7th shooting trial (see Figures III-8 and III-9). In contrast while participating in MOPP-0, DCM and SGT was smaller, corresponding to greater marksmanship accuracy. These measures were also more stable as represented by the lower, flatter lines in Figures III-8 and III-9. Subjects, while shooting with less accuracy in MOPP-1 shot faster in every trial (Figure III-10). Between 3 and 5 hours of testing, sighting time did increase for both clothing conditions but especially in the MOPP-1 condition.

Heart rate at the approximate time of shooting correlated weakly with the various marksmanship measures (Table III-12). However, it may be noted that as heart rate increased so did DCM. As heart rate increased sighting time decreased. Although these correlations are weak they are significant at $p<.05$. The correlations between core temperature and the various marksmanship variables were not significant (Table III-12).

TABLE III-12 Correlations of Heart Rate and Temperatures With Performance Variables

	DCM	SGT	HSGT	VSGT	HDEV	VDEV	STIME	ARM/HAND
HR	.24*	.05	.15	.01	-.10	.09	-.30*	.10
T_a	.02	.16	.17	.15	.12	.12	-.12	.25*

*Significant at $p<0.05$.

The arm-hand steadiness data show that in MOPP-0 an improvement in performance occurred, while in MOPP-1 there was a slight decrement (Figure III-11). These trials took place at night. There was no appreciable rise in ambient temperatures over the course of the study. There was no correlation found between physiological parameters and arm-hand steadiness performance during the night testing.

Figure III-8 Marksmanship Distance from Center of Mass (DCM) by trial and clothing
1 Trial = 30 minutes, (n) = subjects in MOPP-0, [n] = subjects in MOPP-1

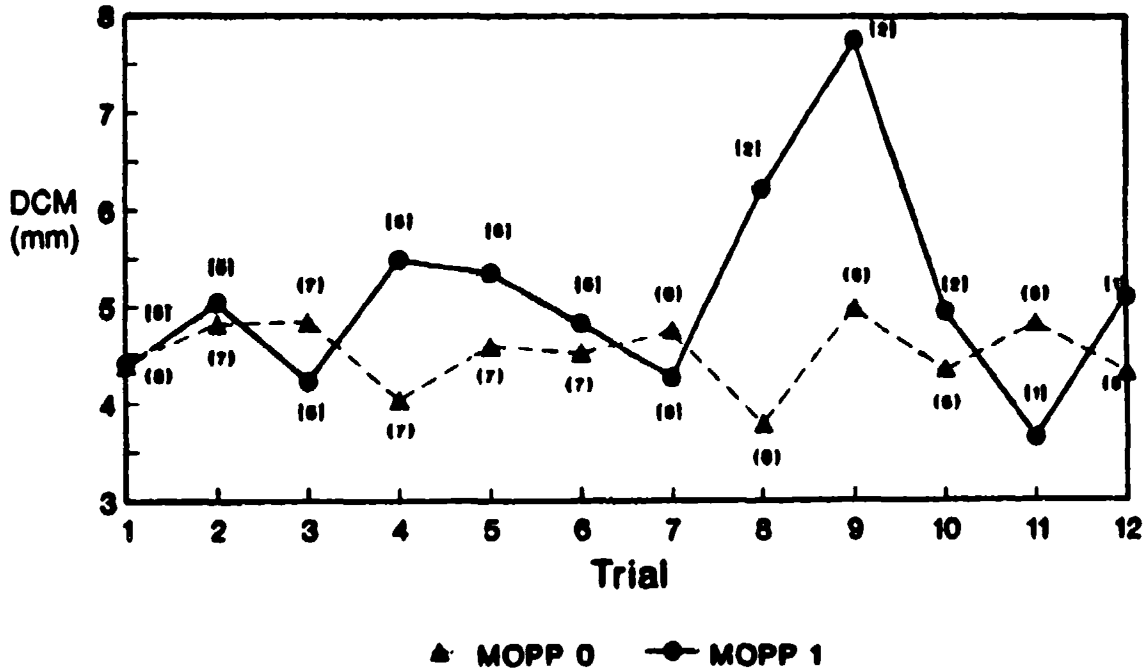


Figure III-9 Marksmanship Shot Group Tightness (SGT) by trial and clothing
1 Trial = 30 minutes, (n) = subjects in MOPP-0, [n] = subjects in MOPP-1

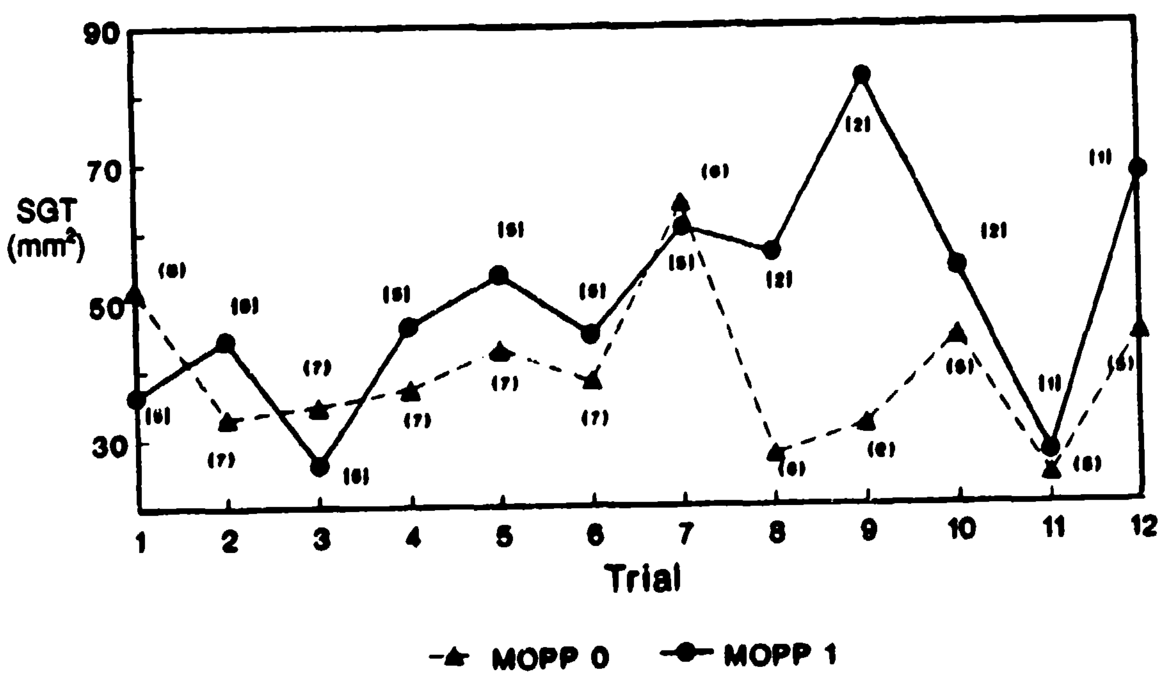


Figure III-10 Marksmanship Sighting Time (ST) by trial and clothing
1 Trial = 30 minutes, (n) = subjects in MOPP-0, [n] = subjects in MOPP-1

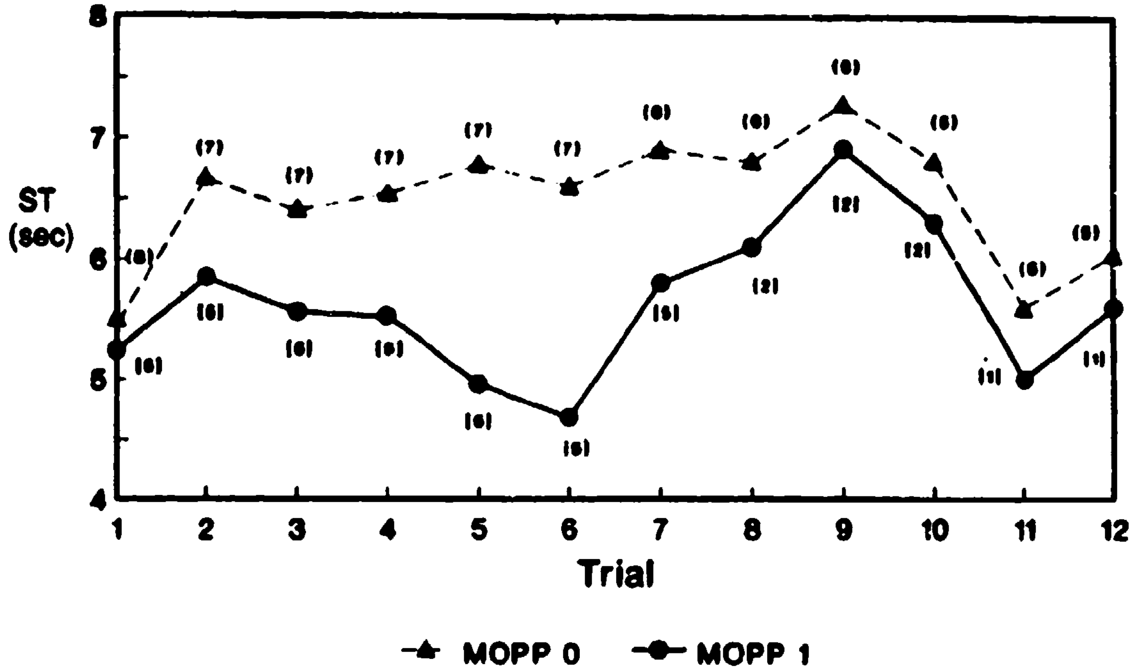
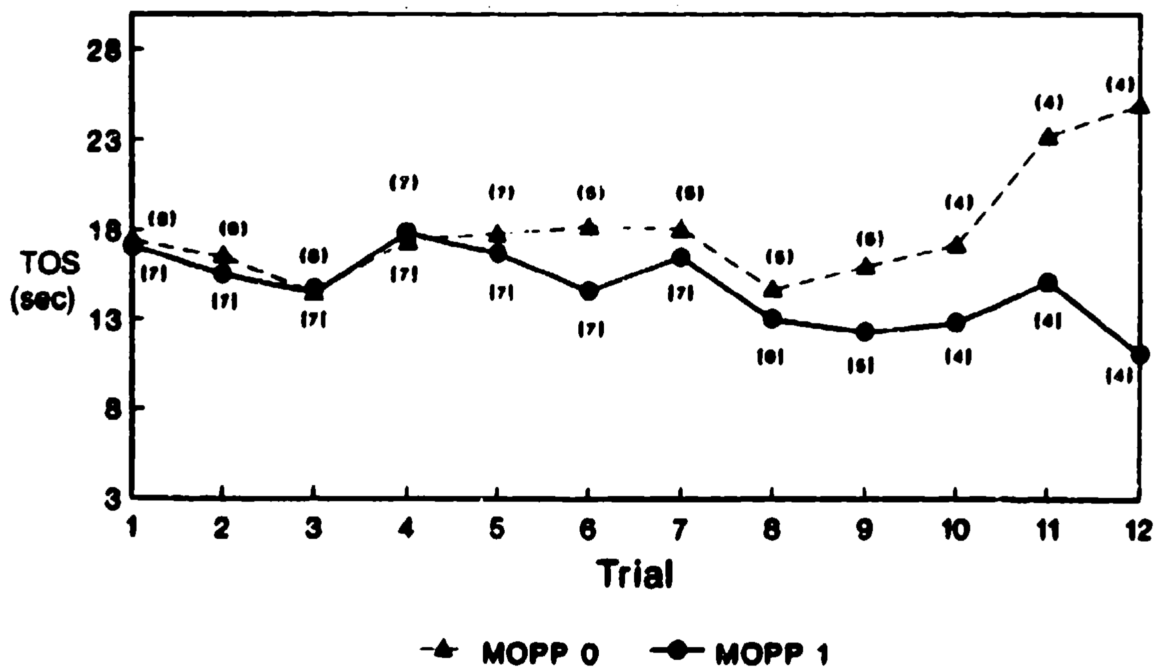


Figure III-11 Arm-hand steadiness by trial and clothing, time off stylus edge (TOS) in seconds, 1 Trial = 30 minutes, (n) = sujetc sin MOPP-0, [n] = subjects in MOPP-1



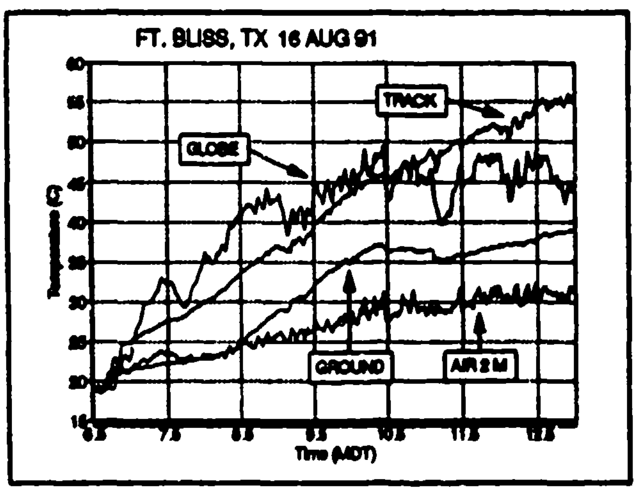
III.D. METEOROLOGY

III.D.1 Meteorological Station Observations

III.D.1.1 General. The observed transitional patterns of temperature, radiation and humidity during the study may be of interest because they illustrate the dynamic variation in the thermal environment as a continuum rather than the spot or mean values normally presented in weather reports or climatological tables. In general, the patterns of individual meteorological parameters are quite logical.

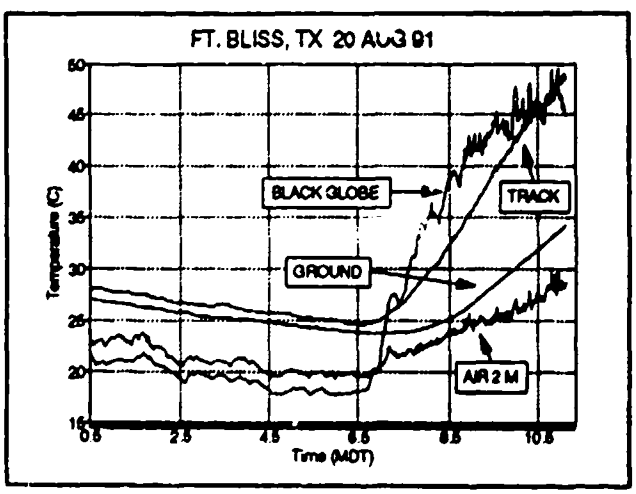
Air temperatures increase during daylight hours and decrease at night. Relative humidity is a function of air moisture and temperature, so fluctuations associated with early morning condensation, light showers, warming or cooling due to changes in solar radiation are normal and broadly predictable.

Figure III-12 Surface and air temperatures during day test



III.D.1.2 Temperature. Detailed meteorological data will be located in the Soldier Performance Database. General data trends include a minimum air temperature near sunrise, and temperature increases as solar radiation increases. Air temperatures at heights between 0.5 and 2 m (not shown) show close agreement indicating that the exact height of temperature measurement was not a critical feature during these test days. Figures III-12 and 13 present the air temperatures at 2 m; averaged track surface temperatures, black globe temperatures and ground probe temperatures for 16 and 20 August 1991. Ground, track surface and globe temperatures rise more rapidly than air temperature due to greater absorption of solar radiation. The black asphalt track surface becomes hotter than the ground (5 cm) probe and the black globe thermometer. The globe demonstrates a rapid response to increasing solar radiation and initially has a higher temperature than the track. However, the track surface temperature exceeds black globe temperature in mid-day due to the greater convective heat loss (wind effect) on the globe. Figure III-12 indicates that the temperature fluctuations in black globe measurements on 16 August 91 due to the radiation component are present, but reduced in magnitude, for the track temperatures. This reflects the moderating effect of the greater mass of the track. The minimum air temperature tends to occur just prior to sunrise, when cumulative heat loss due to "radiational cooling" reaches a maximum value in the absence of solar radiation.

Figure III-13 Surface and air temperature during night test



III.D.1.3 Radiation. Incoming direct, indirect and reflected, sky and ground thermal radiation values are plotted for 17 and 18 August 1991 in Figures III-20 and 21. The plot for 17 August 1991 demonstrates a reasonable scenario of increasing solar radiation after sunrise with the effects of intermittent cloud cover. There was one period of heavy cloud cover near the end of the test period. With that exception, data is very similar to values for 16 August 1991 (not illustrated). Diffuse radiation values for 18 August 1991 are high, suggesting the effects of a thin, broken cloud cover (Monteith, 1973 Powell,1986). Radiation values will be located in the Soldier Performance Database.

Figure III-14 Solar radiation during day test

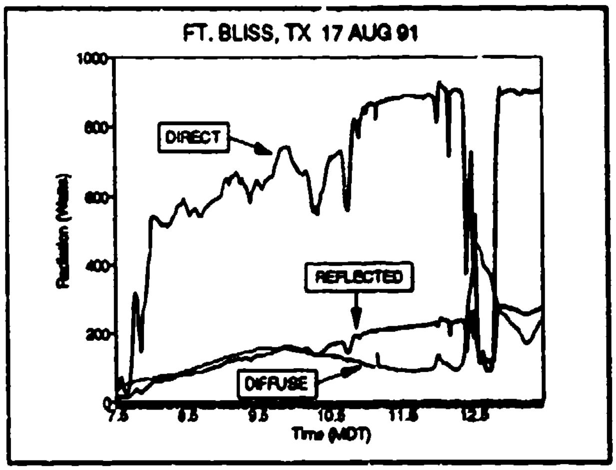
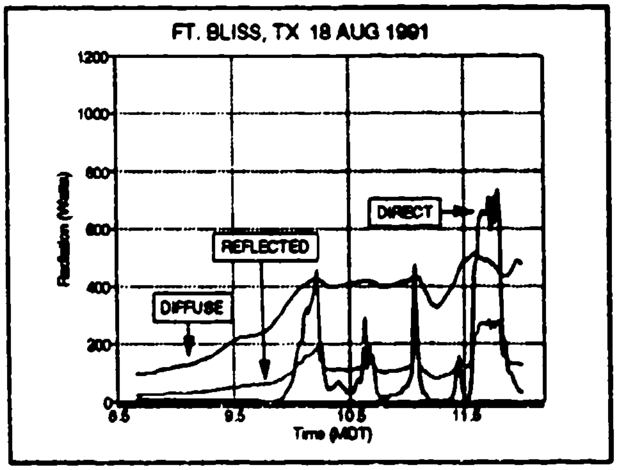
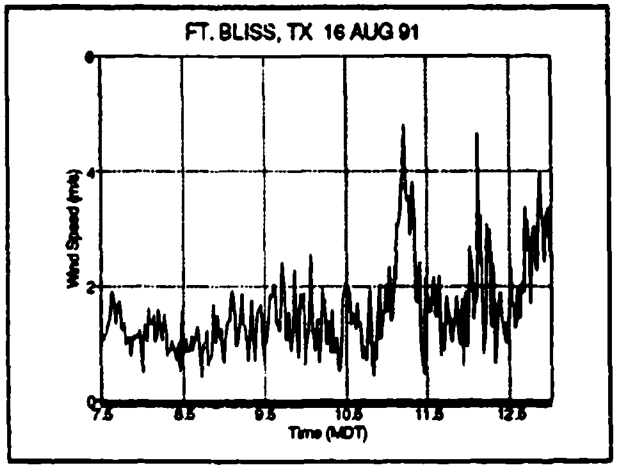


Figure III-15 Solar radiation under scattered cloud cover



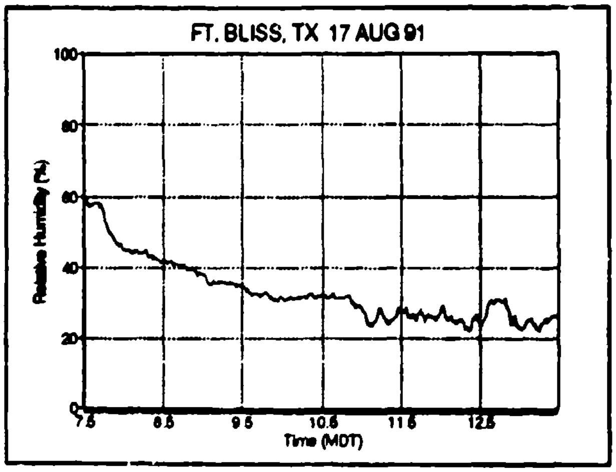
III.D.1.4 Wind Speed. Wind speeds will be located in the Soldier Performance Database. Figure III-16 plots both wind speed for 16 August 1991. The wind speeds at 2 m are generally slightly higher than the values at 1.5 m. This is a normal pattern which can be explained in part by the increase in drag or friction closer to the surface to air interface.

Figure III-16 Wind speed at 1.5 m during day test



III.D.2.5 Humidity. The relative humidity measurements were averaged for the two probes and will be in the Soldier Performance Database. Figure III-17 shows a normal pattern of decreasing relative humidity as air temperature increases during daylight hours.

Figure III-17 Relative humidity during day test



III.D.2 Spatial and Temporal Variation in WBGT

Driven by the daily solar cycle, the 24 hour temporal variation in WBGT exceeded the spatial variation for any given time across the extended study area at McGregor Range. The nighttime WBGT measurements showed remarkably little point-to-point variation. However, there were periods during the day, particularly around solar noon, when we observed substantial point-to-point variation in the 1 minute WBGT values. Figures III-18 through III-20 illustrate typical 24 hour WBGT profiles for the McGregor Range area.

Figure III-18. The 24 hour cycle of 1 minute interval WBGT values from five sites at McGregor Range from noontime on 12 August to noontime on 13 August.

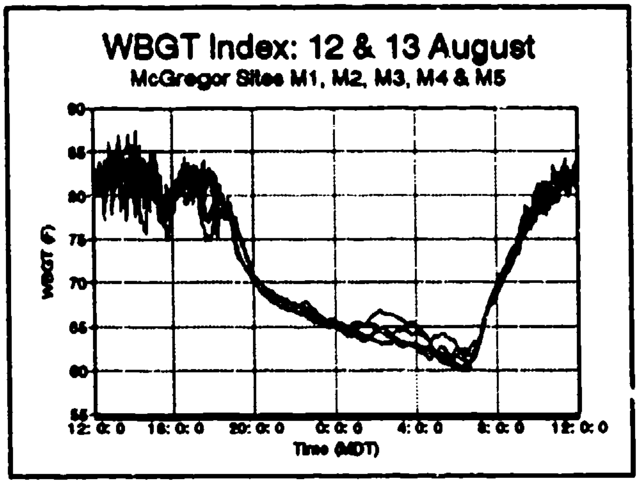
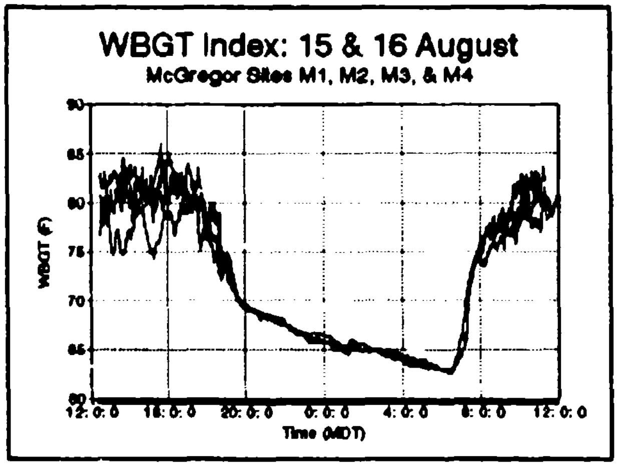


Figure III-18 shows the time course of WBGT index readings over the 24 hour period from noontime on 12 August to noontime on 13 August. In the context of current heat injury prevention guidance for MOPP (FM 21 10, 1988), the range in WBGT values from an average maximum of 84 °F in the early afternoon on 12 August to a minimum of 62 °F around dawn the next day, encompasses five heat stress

categories, including the most severe, Cat 5. The 22 °F span in WBGT readings on 12-13 August establishes the scale of temporal variation that dominates the considerable point-to-point variation we observed in the afternoon across the spatial domain of the 40 km^2 area at McGregor.

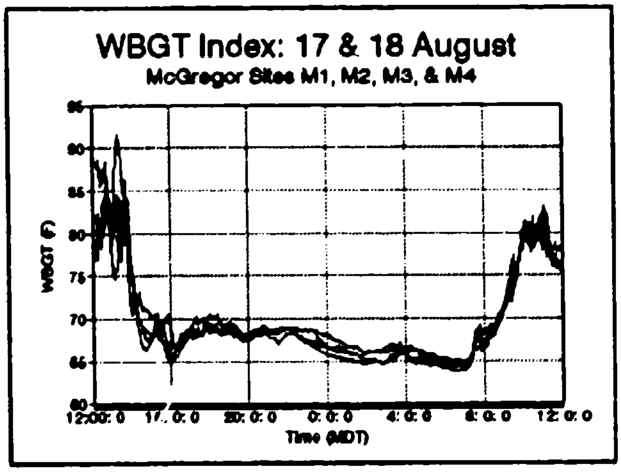
Figure III-19. The 24 hour cycle of 1 minute interval WBGT values from four sites at McGregor Range from noontime on 15 August to noontime on 16 August.



Figures III-19 and III-20 show similar patterns of WBGT for 15-16 August and 17-18 August. Superimposed on a diurnal cycle that includes a period of remarkable spatial uniformity during the nighttime and early morning hours are the short term fluctuations in local WBGT which become most pronounced in the afternoon. Although we do not have direct measurements of wind speed and solar radiation at the McGregor sites, an examination of the minute values for the individual components of the WBGT suggests that most of this instability is attributable to the combined effects of microscale wind speed fluctuations and cloud shadows on the black globe temperature. The air temperature and wet bulb measurements were remarkably stable from minute to minute even during the afternoon hours. At times during the afternoon, simultaneous WBGT readings from the loggers deployed across McGregor

differed by more than 10 °F. However, given the magnitude of the essentially random short term fluctuations at any single site over a 30 minute period, up or down as much as 5 °F, it is tenuous to suggest that physiologically significant contrast in local heat stress conditions, thermal features, existed at McGregor on these afternoons. A more important implication of the high amplitude, transient WBGT fluctuations we observed during the hottest part of the days is the adequacy of sampling strategies for environmental measurements. In practical applications, WBGT or the standard meteorological parameters used for predictive model inputs are typically measured at one hour or half hour intervals based on sampling periods of not more than one or two minutes. Our findings suggest that in the afternoon, sampling or integration times for environmental measurements will have to be extended to at least several minutes to get a reliable assessment of local conditions.

Figure III-20. The 24 hour cycle of 1 minute interval WBGT values from four sites at McGregor Range from noontime on 17 August to noontime on 18 August.



We combined WBGT data from the primary test site at Logan Heights with the McGregor Range data to evaluate spatial variation on a larger scale and to assess the adequacy of an initial 1 minute sample of WBGT to represent average conditions over

a 30 minute period. Tables III-13 and III-14 summarize the temporal and spatial variation in WBGT measurements at Logan Heights and McGregor Range for the time periods of the daytime marches. Results are presented in terms of the heat stress categories for MOPP as described in FM 21-10 (1988). The heat stress categories 1 (low heat injury risk) through 5 (high heat injury risk) were determined from WBGT measurements over time slice intervals of 1 minute and 30 minutes (average of 30 individual 1 minute readings). Tables containing the 30 minute average WBGT values for all test sessions are shown at Appendix A. Because most of the McGregor range WBGT data for the afternoon of 16 August and the morning of 17 August were lost during a computer file transfer operation, data for those two days were combined into a single table.

Regarding short term temporal variation in heat stress conditions, these results indicate that, usually, a heat stress category based on a single one minute WBGT reading, taken on the hour, was within plus or minus one heat stress category of the average for a period that included the next 29 minutes. The important exceptions, on 17 August at McGregor where differences of two heat stress categories were seen, were clearly related to the mid-day instabilities described earlier and to the fact that the WBGT band widths for the higher heat stress categories get progressively smaller: Cat 4 for MOPP is 78.0 to 79.9 °F.

The spatial variation in heat stress environments at the test sites was not large. Using our best assessment of the local environment, the numerical average of the one minute WBGT values over a 30 minute time period for each site, we found one instance of significant contrast (i.e. two or more heat stress categories) in heat stress between Logan Heights (L) and all of the McGregor sites (M1-M4) on 18 August for the final period. Thus, in spite of a generally uniform spatial distribution of heat stress across McGregor Range, the extension of the spatial domain roughly 35 km, to include Logan Heights site, produced a resolvable and potentially significant thermal feature on that larger spatial scale.

Table III-13. Spatial and temporal variation in MOPP heat stress category (FM 21-10, 1988) based on 1 minute and 30 minute average WBGT values at Logan Heights (L) and McGregor Range (M) sites during the daytime marches on 16 and 17 August.

Time Slice	L	M1	M2	M3	M4
16 August					
07:00 07:00 - 07:29 (Avg., n=30)	Cat 1 Cat 1	66.1 Cat 1	64.2 66.7	66.3 Cat 1	66.1 66.9
08:00 08:00 - 08:29	Cat 2 Cat 2	Cat 3 Cat 3	Cat 3 Cat 3	Cat 2 Cat 3	Cat 2 Cat 2
09:00 09:00 - 09:29	Cat 4 Cat 4	Cat 3 Cat 3	Cat 3 Cat 4	Cat 3 Cat 3	Cat 3 Cat 3
10:00 10:00 - 10:29	Cat 5 Cat 5	Cat 4 Cat 5	Cat 5 Cat 5	Cat 4 Cat 4	Cat 3 Cat 4
11:00 11:00 - 11:29	Cat 5 Cat 5	Cat 5 -	Cat 5 Cat 5	Cat 5 Cat 5	Cat 4 Cat 4
17 August					
12:12 12:12 - 12:29*	Cat 5 Cat 5	Cat 5 Cat 5	Cat 5 Cat 5	Cat 3 Cat 5	Cat 5 Cat 5
13:00 13:00 - 13:29	Cat 5 Cat 5	Cat 3 Cat 5	Cat 5 Cat 5	Cat 5 Cat 4	Cat 5 Cat 4

* n=18

Table III-14. Spatial and temporal variation in MOPP heat stress category (FM 21-10, 1988) based on 1 minute and 30 minute average WBGT values at Logan Heights (L) and McGregor Range (M) sites during the MOPP-4 daytime march on 18 August.

Time Slice	L	M1	M2	M3	M4
18 August					
08:00 08:00 - 08:29 (Avg., n=30)	66.8 67.3	Cat 1 Cat 1	66.5 67.6	66.7 67.7	67.1 67.8
09:00 09:00 - 09:29	Cat 1 Cat 1	Cat 1 Cat 2	Cat 1 Cat 2	Cat 1 Cat 2	Cat 1 Cat 2
10:00 10:00 - 10:29	Cat 2 Cat 3	Cat 4 Cat 4	Cat 4 Cat 5	Cat 4 Cat 5	Cat 4 Cat 4
11:00 11:00 - 11:29	Cat 3 Cat 4	Cat 5 Cat 5	Cat 5 Cat 4	Cat 5 Cat 4	Cat 4 Cat 4
12:00 12:00 - 12:29	Cat 3 Cat 4	Cat 4 ---	Cat 3 Cat 3	Cat 3 Cat 3	Cat 3 Cat 3
13:04 13:04 - 13:29 *	Cat 4 Cat 5	Cat 3 Cat 3	Cat 3 Cat 3	Cat 3 Cat 3	Cat 2 Cat 2

* n= 26

III.E. MODEL PERFORMANCE. The P^2NBC^2 Heat Strain Decision Aid T_{re} prediction performance was evaluated for the nighttime march in MOPP-0 and MOPP-1 on 13 August, the daytime march in MOPP-0 and MOPP-1 on 16 August, and the daytime march in MOPP-4 on 18 August.

III.E.1 ENVIRONMENTAL DATA INPUTS. The 30 minute average environmental data were used as inputs to the P^2NBC^2 Heat Strain Decision Aid are shown in Tables III-15 to 17. The listed black globe temperature was used with the measured wind speed and air temperature to determine a Mean Radiant Temperature (T_{mr}) (Kraning, 1991). Environmental data blocks in which the computed T_{mr} values were greater than 25 °C above ambient air temperature were considered to represent a "Full Sun" solar load category for model input.

III.E.2 PREDICTIVE MODEL PERFORMANCE. Table III-18 provides a summary of the model's performance in terms of the magnitude of the error associated with its rectal temperature predictions. The rectal temperature prediction error was computed as the difference between the predicted rectal temperature and the average measured rectal temperature for all subjects in the same clothing ensemble at each sampled minute during the test session. The model's software provided 18 to 21 time indexed T_{re} predictions for each 30 minute block and these were the number (n) of values used in computing the average error and its standard deviation within each time block. Positive error values indicate that the model's predictions are too high and negative error values indicate that the model's predictions are too low.

The accuracy of the P^2NBC^2 Heat Strain Decision Aid T_{re} predictions ranged from -0.32°C (too low) to 0.74 °C (too high) for the 49 half hour time periods we examined. In general, the model appears to overpredict T_{re}, and in this sense, it is conservative as a heat casualty predictor. However, considering that these predictions were propagated out to as much as six hours using an assumed starting T_{re} of 37.0 °C and half hour weather updates, the results are encouraging.

TABLE III-15. 30 minute average values for 1 minute interval meteorological data.

Night March, Logan Heights: 13 August 1991				
Time MDT	Ta °C	RH %	Wind m/s	Globe °C
01:30 - 01:59	24.2	57.1	2.7	23.2
02:00 - 02:29	23.6	62.6	2.8	22.9
02:30 - 02:59	22.9	66.9	1.6	22.4
03:00 - 03:29	22.5	69.0	1.8	21.7
03:30 - 03:59	21.8	73.5	1.6	21.1
04:00 - 04:29	21.3	77.4	1.4	20.3
04:30 - 04:59	21.2	78.6	1.1	20.1
05:00 - 05:29	20.6	80.3	1.2	19.8
05:30 - 05:59	20.6	80.5	1.0	19.5
06:00 - 06:29	20.1	83.2	1.4	19.5
06:30 - 06:59	19.9	83.1	1.6	19.5
07:00 - 07:29	20.5	78.2	1.7	21.0

TABLE III-16. 30 minute average values for 1 minute interval meteorological data.

Day March, Logan Heights: 16 August 1991				
Time MDT	Ta °C	RH %	Wind m/s	Globe °C
07:30 - 07:59	22.9	62.9	1.3	32.2
08:00 - 08:29	24.2	58.0	1.1	36.5
08:30 - 08:59	26.0	48.7	1.0	41.6
09:00 - 09:29	26.7	46.2	1.3	41.0
09:30 - 09:59	28.4	41.7	1.5	43.3
10:00 - 10:29	29.3	37.2	1.2	46.0
10:30 - 10:59	29.5	36.7	1.3	45.5
11:00 - 11:29	29.8	35.1	2.6	43.4
11:30 - 11:59	30.8	32.5	1.4	46.7
12:00 - 12:29	31.3	32.6	1.9	46.4
12:30 - 12:59	31.8	30.2	2.5	46.4

TABLE III-17. 30 minute average values for 1 minute interval meteorological data.

Day March in MOPP-4, Logan Heights: 18 August 1991				
Time MDT	Ta °C	RH %	Wind m/s	Globe °C
08:30 - 08:59	22.3	65.0	1.7	25.3
09:00 - 09:29	22.7	61.3	1.5	26.7
09:30 - 09:59	23.6	54.5	1.9	29.2
10:00 - 10:29	25.8	42.4	1.2	38.7
10:30 - 10:59	27.7	40.2	1.1	39.9
11:00 - 11:29	26.5	44.0	2.3	37.0
11:30 - 11:59	26.9	41.6	3.7	39.9

Table III-18. Summary of the model's rectal temperature prediction performance for the night march on 13 August and the day marches on 16 and 18 August.

MODEL PREDICTION ERROR, °C (Tre predicted - Tre measured)					
	Night March: 13 August		Day Marches: 16 and 18 August		
30' Period	MOPP-0	MOPP-1	MOPP-0	MOPP-1	MOPP-4
1	-0.32 ±0.04	-0.22 ±0.12	-0.13 ±0.15	-0.06 ±0.24	0.03 ±0.14
2	-0.31 ±0.05	-0.01 ±0.10	0.18 ±0.09	0.35 ±0.08	0.31 ±0.12
3	-0.24 ±0.05	0.20 ±0.07	0.35 ±0.07	0.43 ±0.02	0.48 ±0.05
4	-0.21 ±0.04	0.35 ±0.06	0.46 ±0.03	0.33 ±0.05	0.57 ±0.07
5	-0.16 ±0.07	0.43 ±0.06	0.50 ±0.04	0.20 ±0.05	0.57 ±0.04
6	-0.07 ±0.03	0.51 ±0.05	0.45 ±0.05	0.18 ±0.11	0.51 ±0.06
7	-0.10 ±0.02	0.58 ±0.04	0.36 ±0.05		0.33 ±0.07
8	-0.13 ±0.02	0.64 ±0.04	0.30 ±0.04		
9	-0.17 ±0.03	0.68 ±0.05	0.15 ±0.12		
10	-0.23 ±0.02	0.74 ±0.03	0.31 ±0.24		
11	-0.26 ±0.02	0.66 ±0.03	0.46 ±0.14		
12	-0.19 ±0.10	0.64 ±0.05	0.42 ±0.01		
OVERALL	-0.20 ±0.20	0.43 ±0.30	0.31 ±0.20	0.24 ±0.19	0.42 ±0.18

IV. DISCUSSION

IV.A. PHYSIOLOGICAL PARAMETERS

IV.A.1 Rectal Temperature

No subject reached the rectal temperature limit of 39.0°C during any test session and rectal temperatures for the night test sessions show that subjects did not experience significant heat strain during nighttime tests. Table III-5 and Figures 3 through 5 clearly indicate that chemical protective clothing does increase the thermal burden on test subjects in thermally stressful environments. Using data from this study, Matthew and Santee (1992) show there are sufficient differences in environmental conditions between 16 and 17 August to elicit very distinct differences in rectal temperature response. During a 3 hour time period (07:30 to 10:30 MST), average air temperature was 0.3°C cooler, but relative humidity was 9.6% higher and wind speed was 1.3 $m \cdot s^{-1}$ lower on 16 August. As reported, those differences in environmental parameters resulted in an average rate of raise in rectal temperature on 16 August for load-bearing was $0.54°C \cdot hr^{1}$ (n=3) versus $0.28°C \cdot hr^{1}$ (n=2) on 17 August over the same time period. Those results demonstrate why it would be inappropriate to combine data from those two days for statistical analysis without the application of correction factors to adjust for the differences in environmental conditions. It would also be inappropriate to statistically compare data between MOPP-0, MOPP-1 and MOPP-4 levels of chemical protection without compensating for environmental variability between the test sessions.

Some documentation (USARIEM Technical Note 91-2, 1990, Appendix B, Table B-1) implies that MOPP-1 does not significantly increase thermal stress relative to MOPP-0, but when worn closed (zipped) over the BDU, MOPP-1 is essentially

equivalent to MOPP-2 which is acknowledged to significantly impact soldier performance in warm environments. This is not new information, and it was an assumption of the study that chemical protective clothing would impair thermoregulation.

IV.A.2 Skin Temperatures

There is insufficient information to make a specific conclusion regarding the impact of different levels of MOPP on skin temperature. Data from the first night test (13 August) supports the concept that CP clothing provided additional insulation which allowed subjects to stay warmer.

IV.A.3 Water consumption

Data from the first night test indicate that subjects in MOPP-1 lost more water than subjects in MOPP-0 (0.071 vs 0.104 $gm \cdot min^{-1} \cdot kg^{-1}$). However data would also indicate that subjects in MOPP-4 lost water at a rate (0.186 $gm \cdot min^{-1} \cdot kg^{-1}$) which was intermediate between MOPP-0 (0.158 $gm \cdot min^{-1} \cdot kg^{-1}$) and MOPP-1 (0.248 $gm \cdot min^{-1} \cdot kg^{-1}$). As indicated in the modeling section, these data cannot be quantitatively compared because the thermal stress experienced by subjects differed between daylight test days. In addition, the duration of exposure was also a factor.

Data on gross water consumption (Table III-10) may be misleading. Several subjects tended to drink water over relatively short periods of time, especially in response to encouragement from the test staff and medical monitors, rather than sipping over extended periods of time. In those cases, apparent water consumption was strongly influenced by the time of subject withdrawal relative to the consumption episode. For example, subject 4a consumed 1 liter of water, but withdrew after 18

minutes on 20 AUG 92. At a calculated consumption rate of 0.056 $l \cdot min^{-1}$,(1 liter per 18 minutes), the subject would consume 19.7 l in 354 minutes of participation. During his other night test, the same subject drank 2.7 l in 354 min.

IV.A.4 Endurance

General tendencies regarding subject endurances could not be validated statistically because there were sufficient environmental differences between test days. For the daytime MOPP-1 condition, only one subject essentially completed the 12 mile march. For the daytime MOPP-4 condition, the longest endurance time was 3 hours and 24 minutes. Based on 14 August data, subjects walked longer in the more moderate night environment. Subject performance on 20 August was influenced by the apparent decline in subject motivation and was not representative of their full potential. Subjects walked longer while wearing MOPP-0 level of CP, relative to MOPP-1 and MOPP-4. Although no valid statistical comparison is possible, due to differences in environmental conditions, subjects walked longer in MOPP-1 than MOPP-4. Problems with the masks may confound those observations, but the basic observation is consistent with other dogma comparing MOPP-1 to MOPP-4 levels of protection.

IV.B. MARKSMANSHIP PERFORMANCE

The performance tests related to marksmanship indicate there was a cumulative effect of time in both night and day tests. Marksmanship (daylight test) sighting time and DCM were correlated to uniform (MOPP-0 vs. MOPP-1) and the length of time walked. After 3.5 hours of walking in MOPP-1 accuracy began to deteriorate. Marksmanship performance was weakly correlated to subject heart rate and rectal

temperature. During night tests, the environment was not thermally stressful. Consequently the absence of a strong correlation between physiological parameters and arm-hand steadiness is neither surprising nor conclusive.

IV.C. METEOROLOGY

Although predictable in terms of general pattern, it cannot be overemphasized that actual daytime environments are very dynamic. In the absence of solar radiation, night environments tend to be more stable. The authors attribute the difference primarily to the presence or absence of solar radiation. The data reflect the importance of real environmental conditions. Daily patterns of solar radiation, temperature, humidity and wind, especially in context of daily variations in same, may easily be as important or more important than clothing in terms of thermal stress. The value of this study lies in the contrast between the highly variable, dynamic meteorological observation at the test site and the stable, essentially static conditions in the environmental chambers.

IV.D. METEOROLOGY AND MODELING

A significant problem with using a model to predict heat strain is related to the dynamic nature of the environment. The situation is directly analogous to a weather forecast. In rather simplistic terms, the closer to an event the input observations are collected, the more accurate the prediction or forecast. If a forecast is made a year in advance, only the general guidance of cumulative climatic data is applicable. As data closer to the event becomes available, the forecast becomes more accurate. Forecasts improve in accuracy for thirty day, five day, three day and next day forecasts.

The heat strain prediction model is dependent on the quality of the input data. If only average climatic data are used for input, the output is most accurate if the actual day of the event has the exact same conditions. If data from the previous half hour are used as input, the forecast for the next half hour is much more likely to be quite accurate. Model performance generally improves with the quality of the meteorological inputs. USARIEM has initiated the development of "individual heat stress monitors" which can be used to provide an immediate, local measurement of environmental conditions for direct input into the heat strain prediction model.

IV.E. TEMPORAL AND SPATIAL VARIATION IN HEAT STRESS ENVIRONMENTS

Whether environmental measurements are used to compute a simple heat stress index or serve as inputs for a more sophisticated thermal strain prediction model, a fundamental task is to establish practical measurement strategies that allow us to effectively quantify the severity of heat stress environments that are potentially very dynamic with respect to time and place. Not surprisingly, at the temporal and spatial scales we examined at Fort Bliss during this study, the impact of the daily solar cycle on surface level air mass heating and cooling dominates the 24 hour heat stress environments. In spite of the large daily range in ambient air temperature and relative humidity over a 24 hour period, the minute to minute variation in these meteorological parameters was quite small. Our results suggest that a single 1 minute measurement "sample" of air temperature and humidity provides values that are generally comparable with average values taken over the next 30 minutes. Conversely, wind speed and solar radiation measurements showed substantial variation from one minute to the next. The implication for heat stress prediction model applications which use standard measured meteorological parameters in real time environments is that substantial uncertainty in predicted values will be introduced if the measurement sampling periods for wind speed and solar radiation are 1 minute or less.

IV.F PREDICTIVE MODEL PERFORMANCE.

The overall performance of the P^2NBC^2 Heat Strain Decision Aid in predicting extended time series T_{re} profiles was reasonably good. Overall average T_{re} prediction errors for the MOPP-0, MOPP-1, and MOPP-4 marches ranged from -0.20 °C (too low) to 0.43 °C (too high). The absolute worst case T_{re} prediction error, 0.74 °C too high, occurred 5 hours into the modeling run for the night march in MOPP-1 on 13 August. Given that work rate and clothing ensemble were rigorously controlled and the uncertainties in the environmental inputs for the modeling runs were reduced to a practical minimum, this limited preliminary assessment nevertheless provides a reasonable indication of the current intrinsic fidelity of the model in a dynamic natural environment. It is anticipated that the comprehensive environmental and physiological data collected during this study, in combination with data from other studies, will afford more definitive evaluations of the model across a wider range of environments and scenarios.

V. SUMMARY

The primary purpose of this study was to expand the database on soldier performance in natural environments. No subject was withdrawn due to exceeding the pre-selected maximum core temperature or maximum heart rate limits. For the daytime MOPP-1 condition, only one subject essentially completed the 12 mile march. For the daytime MOPP-4 condition, the longest endurance time was 3 hours and 24 minutes. There appears to be a clear contrast in soldiers' physiological responses between MOPP-0 and MOPP-1 conditions during daylight activities, but due to differences between test period environments, there is no statistical support for that conclusion. Our results indicate that physiological heat strain at night, for the test scenario, was minimal. There was an indication that gross water loss was lower during night activity relative to daylight activity.

The performance tests related to marksmanship indicate that there was a cumulative effect of time in both night and day tests. Marksmanship (daylight test) sighting time and DCM were correlated to uniform (MOPP-0 vs. MOPP-1) and the length of time walked. After 3.5 hours of walking in MOPP-1 accuracy began to deteriorate. Marksmanship performance was weakly correlated to subject heart rate.

The data reflect the importance of real environmental conditions. Diurnal patterns of solar radiation, temperature, humidity and wind, especially in context of daily variations in same, are important. Although predictable in terms of general pattern, actual daytime environments are very dynamic. In this study, night environments tended to be more stable. There was general agreement, varying within an overall mean prediction error of -0.20 to 0.43°C, between observed subject rectal temperatures (T_{re}) and results predicted from the P^{2}NBC^2 Heat Strain Decision Aid (HSDA).

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APPENDIX A. McGREGOR RANGE WBGT DATA

Table 1. Spatial and temporal variation in 1 minute and 30 minute average WBGT values at Logan Heights (L) and McGregor Range (M) sites during the nighttime march on 13 August. Bolded values are those that differed by 2 °F or more from the 1 minute observation at Logan Heights.

Time Slice	L	M1	M2	M3	M4	M5
01:00	68.1	**64.4**	**64.1**	**65.4**	**64.5**	**64.5**
01:00 - 01:29 (Avg., n=30)	68.0	**64.0**	**63.6**	**65.4**	**64.2**	**64.9**
02:00	68.3	**63.4**	**64.8**	66.4	**64.3**	**65.2**
02:00 - 02:29	68.1	**63.2**	**64.7**	66.5	**64.4**	**64.6**
03:00	67.8	**63.6**	**63.1**	66.1	**63.4**	**64.4**
03:00 - 03:29	67.5	**63.3**	**62.8**	**65.8**	**63.1**	**64.5**
04:00	66.9	**63.0**	**62.5**	65.1	**62.8**	**64.4**
04:00 - 04:29	66.7	**62.7**	**62.1**	**64.6**	**62.6**	**64.0**
05:00	66.2	**62.0**	**61.6**	**64.0**	**61.7**	**62.0**
05:00 - 05:29	65.8	**61.8**	**61.1**	**64.0**	**61.5**	**62.4**
06:00	65.8	**62.4**	**60.3**	**62.8**	**60.8**	**61.7**
06:00 - 06:29	65.6	**62.3**	**60.1**	**62.0**	**60.6**	**61.3**
07:00	65.8	**62.7**	**62.3**	**62.9**	**62.4**	**62.0**
07:00 - 07:29	66.2	64.3	63.9	64.7	64.1	64.0

Table 2. Spatial and temporal variation in 1 minute and 30 minute average WBGT values at Logan Heights (L) and McGregor Range (M) sites during the nighttime march on 20 August. Bolded values are those that differed by 2 °F or more from the 1 minute observation at Logan Heights.

Time Slice	L	M1	M2	M3	M4
01:00	66.9	65.7	63.1	63.2	62.5
01:00 - 01:29 (Avg., n=30)	67.0	65.2	62.3	62.9	62.2
02:00	66.7	64.5	62.8	63.1	62.0
02:00 - 02:29	66.1	64.3	62.7	63.4	62.7
03:00	65.4	65.1	63.6	64.2	63.3
03:00 - 03:29	65.6	64.7	63.2	64.5	63.3
04:00	65.5	64.2	61.7	63.1	62.1
04:00 - 04:29	65.0	64.0	61.7	62.7	61.8
05:00	64.6	64.3	61.8	62.5	61.6
05:00 - 05:29	64.4	64.1	61.7	62.3	61.6
06:00	64.2	63.3	61.5	62.5	62.6
06:00 - 06:29	64.4	63.4	61.1	62.4	62.4
07:00	66.5	65.6	63.3	65.2	64.6
07:00 - 07:29	68.5	67.7	64.9	67.6	67.3

Table 3. Spatial and temporal variation in 1 minute and 30 minute average WBGT values at Logan Heights (L) and McGregor Range (M) sites during the daytime marches on 16 and 17 August. Bolded values are those that differed by 2 °F or more from the 1 minute observation at Logan Heights.

Time Slice	L	M1	M2	M3	M4
16 August					
07:00 07:00 - 07:29 (Avg., n=30)	68.6 **71.9**	**66.1** 69.1	**64.2** 66.7	**66.3** 69.2	**66.1** 66.9
08:00 08:00 - 08:29	74.9 76.1	75.5 76.6	75.5 76.3	74.3 75.9	74.3 74.1
09:00 09:00 - 09:29	79.6 78.9	**77.1** 77.7	77.8 78.6	**77.3** **77.3**	**75.8** **76.5**
10:00 10:00 - 10:29	80.3 81.7	**78.0** 80.7	81.0 81.6	78.3 78.8	**77.8** 78.9
11:00 11:00 - 11:29	81.4 80.1	80.9 -	83.1 82.4	81.5 80.3	**78.0** **78.8**
17 August					
12:12 12:12 - 12:29*	84.2 83.6	81.7 **80.7**	**88.0** **87.2**	**76.8** **80.3**	**80.0** **81.0**
13:00 13:00 - 13:29	86.0 85.1	**75.5** **80.3**	**83.2** **89.2**	**82.5** **78.6**	**82.6** **78.7**

*n=18

Table 4. Spatial and temporal variation in 1 minute and 30 minute average WBGT values at Logan Heights (L) and McGregor Range (M) sites during the MOPP-4 daytime march on 18 August. Bolded values are those that differed by 2 °F or more from the 1 minute observation at Logan Heights.

Time Slice	L	M1	M2	M3	M4
08:00	66.8	68.2	66.5	66.7	67.1
08:00 - 08:29 (Avg., n=30)	67.3	**68.8**	67.6	67.7	67.8
09:00	68.9	68.7	68.5	68.5	68.5
09:00 - 09:29	69.5	**74.2**	**73.7**	**72.1**	**73.2**
10:00	72.8	**78.1**	**79.5**	**79.8**	**79.4**
10:00 - 10:29	**75.9**	**79.4**	**80.2**	**80.2**	**79.4**
11:00	76.3	**81.1**	**80.8**	**80.3**	**78.4**
11:00 - 11:29	**79.5**	**80.5**	**79.7**	**78.2**	**78.9**
12:00	76.8	78.1	76.7	75.9	76.0
12:00 - 12:29	**79.0**	---	76.1	76.8	76.6
13:04	78.8	76.9	**76.3**	**76.8**	**74.4**
13:04 - 13:29 *	**81.2**	76.9	**75.2**	**75.8**	**74.4**

n= 26

Table 5. Satellite passes with concurrent ground truth data.

Spacecraft	Date & Time of Overpass (MDT)	Track Site Loggers	McGregor Site Loggers	Subjects on Track
NOAA-10	08/11 08:03:21	3	0	BDU Accl
NOAA-11	08/12 04:00:02	3	0	BDU Accl
NOAA-10	08/12 09:19:41	3	0	
NOAA-11	08/12 15:27:11	3	5	
NOAA-10	08/12 20:30:02	0	5	
NOAA-11	08/13 03:54:22	3	5	BDU/MOPP
NOAA-11	08/13 15:15:40	0	4	
NOAA-10	08/13 20:12:11	1	4	
NOAA-11	08/14 03:42:50	0	4	
NOAA-10	08/14 08:33:04	0	4	
NOAA-11	08/14 15:04:10	0	4	
NOAA-10	08/14 19:48:46	0	4	
NOAA-11	08/15 03:31:16	0	4	
NOAA-10	08/15 08:09:39	3	4	
NOAA-10	08/15 19:25:27	1	4	
NOAA-11	08/16 03:19:41	1	4	
NOAA-11	08/16 14:41:13	3	0	
NOAA-11	08/17 04:48:43	1	0	
NOAA-10	08/17 09:02:39	3	0	BDU/MOPP
NOAA-10	08/17 20:18:28	0	4	
NOAA-11	08/18 04:37:15	0	4	

Table 5 (continued). Satellite passes with concurrent ground truth data.

Spacecraft	Date & Time of Overpass (MDT)	Track Site Loggers	McGregor Site Loggers	Subjects on Track
NOAA-10	08/18 08:39:20	3	4	MOPP-4
NOAA-11	08/18 15:58:54	3	4	
NOAA-10	08/18 19:55:02	1	4	
NOAA-11	08/19 04:25:46	0	4	
NOAA-10	08/19 08:15:56	1	4	
NOAA-11	08/19 15:47:09	1	4	
NOAA-11	08/20 04:14:16	3	4	BDU/MOPP
NOAA-12	08/20 09:34:01	0	4	

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